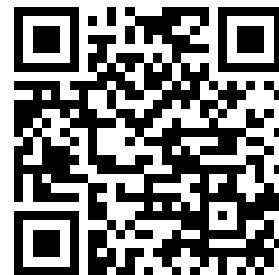
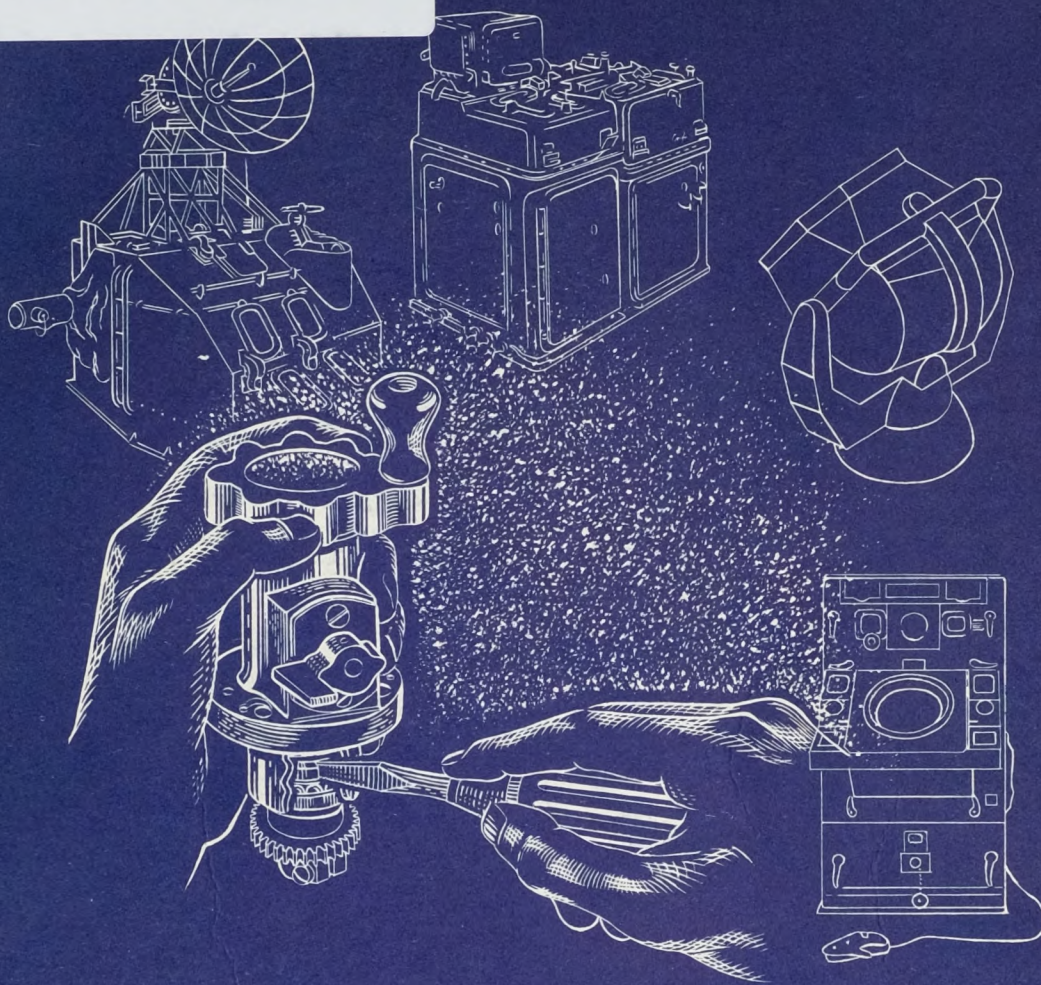

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FIRE CONTROL TECHNICIAN 1 & C

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NAVY TRAINING COURSE

NAVPERS 10175



PREFACE

This Navy Training Course was written to serve as an aid for enlisted men of the U.S. Navy and U.S. Naval Reserve who are preparing for advancement to the rates of Fire Control Technician G (gun fire control) 1, Fire Control Technician M (missile fire control) 1, and Chief Fire Control Technician. It is one of a series of Navy Training Courses designed to give enlisted men background information necessary for the proper performance of the duties of their rate. The level of the material introduced in each training course is programmed to be concurrent with the rate level. Hence, this course leans heavily on material contained in previous courses of the series and related publications. The related literature is listed in the reading list in the front of this book.

The predominant factor in the selection of content for this publication has been the Manual of Qualifications for Advancement in Rating, Nav-Pers 18068-A as revised in 1963. The knowledge factors in the qualifications are based on the theory of fire control equipment. The material in this course covers this area by dealing with the underlying theory of the equipment. This approach allowed the coverage of gun and missile fire control units in a single volume. Moreover the additional benefit of keeping the course unclassified and therefore more available was derived by this approach.

This book was prepared by the U.S. Navy Training Publications Center for the Bureau of Naval Personnel. Special credit is given to the Bureau of Naval Weapons and to the Fire Control Technician Schools, Great Lakes, Illinois, for assisting in the technical review of the text.

1964 Edition

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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READING LIST

NAVY TRAINING COURSES

Mathematics, Volume 1, NavPers 10069-B
Basic Electricity, NavPers 10086-A
Basic Electronics, NavPers 10087-A
Fire Control Tech 3, NavPers 10173-A
Fire Control Tech 2, NavPers 10174-A
Guided Missiles and Nuclear Weapons (chapter 1-7), NavPers 10785
Principles of Naval Ordnance and Gunnery,
(chapters 5, 7, 8, 12, 13) NavPers 10783-A

OTHER PUBLICATIONS

Weapons Systems Fundamentals, Volumes 1, 2, and 3, OP 3000
Lubrication of Ordnance Equipment, OD 3000
Handbook of Test Methods and Practices
(Articles 3-7 through 3-11), NavShips 91828-A

USAFI COURSES

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Educational Services Officer. *A partial list of those courses applicable to your rate follows:

Number

C 151	General Mathematics I
C 152	General Mathematics II
C 781	Fundamentals of Electricity

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

CHAPTER 1

BROADER HORIZONS

This course is written to assist the FT2 to advance in rate to FT1 and to aid the FT1 to advance to FTC. The course deals primarily with the professional (technical) qualifications for FT1 and FTC as listed in the 1963 revision of the Manual of Qualifications for Advancement in Rating, NavPers 18068-A. Any change in qualifications occurring after this revision may not be reflected in the information given in this course.

Military requirements are covered in the current edition of Military Requirements for Petty Officers 1 & C, NavPers 10057-A.

Chapter 2 presents the information needed to calculate ballistics data for the fire control problem.

Chapter 3 discusses the analog computers used in the fire control systems.

Chapter 4 encompasses the Weapons Control System, its unit functions, relationship between units, and system operation.

Chapter 5 discusses power drives for fire control directors and radars.

Chapter 6 discusses the physical and electrical alignment of ordnance equipment aboard ship, both the conventional weapons and guided missile batteries.

Chapter 7 deals with spotting of naval gunfire and naval gunfire support.

Chapter 8 discusses waveguides and cavity resonators used in fire control radars.

Chapter 9 discusses special radar components used with microwave frequencies.

Chapter 10 covers the principal of radar antennas and the types of antennas used in fire control radars.

Chapter 11 discusses maintenance administration and supply information used in the weapons department aboard ship, including such maintenance programs as IMP and Standard Navy Maintenance Management program.

Chapter 12 discusses components and circuits used in a weapons direction system.

Chapter 13 presents some of the test equipment used with fire control equipment.

The remainder of this chapter contains information that will help you in preparing for advancement. It is strongly recommended that you study this chapter carefully before beginning intensive study of the remainder of this training course.

THE ENLISTED RATING STRUCTURE

The present enlisted rating structure, established in 1957, includes three types of ratings: general ratings, service ratings, and emergency ratings.

GENERAL RATINGS are designed to provide paths of advancement and career development. A general rating identifies a broad occupational field of related duties and functions requiring similar aptitudes and qualifications. General ratings provide the primary means used to identify billet requirements and personnel qualifications. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

Subdivisions of certain general ratings are identified as SERVICE RATINGS. These service ratings identify areas of specialization within the scope of a general rating. Service ratings are established in those general ratings in which specialization is essential for efficient utilization of personnel. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

EMERGENCY RATINGS identify essentially civilian occupations. Emergency ratings are not identified as ratings in the peacetime Navy, but their identification is required in time of war.

THE FIRE CONTROL TECHNICIAN 1 & C RATINGS

At the FT3, FT2, and FT1 levels, the fire control technician rating is divided into service ratings—FTG (gun fire control), and FTM (missile fire control). At the E-7 level, the FT rating becomes a general rating, encompassing both the FTG and the FTM knowledge. From this you can see that the FT1 must broaden his scope of training to include both the FTG and the FTM equipments. Also the FTC must include in his training programs information for cross-training FTGs and FTMs.

There are many interesting and rewarding types of billets, besides the regular sea billets, open to senior fire control technicians. Some of these include instructor billets at "A," "B," "C," and guided missile schools; writing of training publications at the U. S. Navy Training Publications Center, Washington, D. C.; members of U. S. Naval Missions and Military Assistance Advisory Groups in various allied countries; instructors in the Naval Reserve Officers Training (NROTC) programs at various colleges and universities; and instructors at Naval Reserve Training Centers.

As a junior petty officer you are already a leader, but as you advance to first class and chief petty officer your leadership responsibilities increase. It will become your duty to set the examples of courage, subordination, zeal, sobriety, neatness, and attention to duty, as stated in General Order No. 21, for your juniors to follow. Chapter 2 of Military Requirements for Petty Officer 1 & C, NavPers 10057-A, gives a detailed discussion of the senior petty officers' responsibilities in matters of leadership. This chapter should be read frequently and the principles applied where and when necessary.

As you advance in your rating you will also have increasing responsibility for supervising, instructing, and training other men. As a senior FT you will be required to organize and supervise the work and training of lower rated men in all phases of maintenance and repair of fire control equipment.

As a senior petty officer you must take a great deal of responsibility in the matter of SAFETY. It is your business to know and observe all the safety precautions appropriate to the job you are doing or to the equipment you are working with. In addition, it is your responsibility to make sure that men working under your

supervision also observe all safety precautions. Safety precautions shall always be taught as part of any instructional program.

ADVANCEMENT IN RATING

By this time, you are probably well aware of the personal advantages of advancement in rating—higher pay, greater prestige, more interesting and challenging work, and the satisfaction of getting ahead in your chosen career. By this time, also, you have probably discovered that one of the most enduring rewards of advancement is the training you acquire in the process of preparing for advancement.

The Navy also profits by your advancement. Highly trained personnel are essential to the functioning of the Navy. By each advancement in rating, you increase your value to the Navy in two ways. First, you become more valuable as a technical specialist in your own rating. And second, you become more valuable as a person who can supervise, lead, and train others and thus make far-reaching contributions to the entire Navy.

Since you are studying for advancement to PO1 or CPO, you are probably already familiar with the requirements and procedures for advancing in rating. However, you may find it helpful to read the following sections. The Navy does not stand still. Things change all the time, and it is possible that some of the requirements have changed since the last time you were going up for advancement in rating. Furthermore, you will be responsible for training others for advancement, and so will need to know the requirements in some detail.

HOW TO QUALIFY FOR ADVANCEMENT

To qualify for advancement in rating, a person must:

1. Have a certain amount of time in grade.
2. Complete the required military and professional training courses.
3. Demonstrate the ability to perform all the PRACTICAL requirements for advancement by completing applicable portions of the Record of Practical Factors, NavPers 760.
4. Be recommended by his commanding officer.
5. Demonstrate his KNOWLEDGE by passing a written examination on (a) military requirements, and (b) professional qualifications.

Some of these general requirements may be modified in certain ways. Figure 1-1 gives an overall view of the requirements for advancement of active duty personnel; figure 1-2 gives this information for inactive duty personnel.

Remember that the requirements for advancement can change. Check with your division officer or training officer to be sure that you know the most recent requirements.

When you are training lower rated personnel, it is a good idea to point out that advancement in rating is not automatic. Meeting all the requirements makes a person ELIGIBLE for advancement, but it does not guarantee his advancement. Such factors as the score made on the written examination, length of time in service, performance marks, and the quotas for the rating enter into the final determination of who will actually be advanced.

HOW TO PREPARE FOR ADVANCEMENT

Preparations for advancement in rating include studying the qualifications, working on the practical factors, studying the required Navy Training Courses, and studying any other material that may be specified for the rate and rating. To prepare for advancement yourself or to help others prepare for advancement, you will need to be familiar with (1) the Quals Manual, (2) the Record of Practical Factors, NavPers 760, (3) a NavPers publication called Training Publications for Advancement in Rating, NavPers 10052, and (4) Navy Training Courses. The following sections describe these materials and give some information on how to use them to best advantage.

The Quals Manual

The Manual of Qualifications for Advancement in Rating, NavPers 18068A (with changes), gives the minimum requirements for advancement to each rate within each rating. This manual is usually called the "Quals Manual," and the qualifications themselves are often called "quals." The qualifications are of two general types: (1) military requirements, and (2) professional or technical qualifications. Military requirements apply to all ratings rather than to any one rating alone. Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject

matter groups. Then, within each subject matter group, they are divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS.

The professional qualifications for advancement in your rating covered in this training course were current at the time this training course was printed. However, the Quals Manual is changed more frequently than Navy Training Courses are revised. By the time you are studying this training course, therefore, the quals for your rating may have been changed. Never trust any set of quals until you have checked it against an UP-TO-DATE copy in the Quals Manual.

In training others for advancement in rating, emphasize these three points about the quals:

1. The quals are the MINIMUM requirements for advancement to each rate within the rating. Personnel who study MORE than the required minimum will have a great advantage when they take the written examinations for advancement.

2. Each qual has a designated rate level—chief, first class, second class, or third class. You are responsible for meeting all quals specified for the rate level to which you are seeking advancement AND all quals specified for lower rate levels.

3. The written examinations for advancement in rating will contain questions relating to the practical factors AND to the knowledge factors of BOTH the military requirements and the professional qualifications.

Record of Practical Factors

A special form known as the RECORD OF PRACTICAL FACTORS, NavPers 760, is used to record the satisfactory performance of the practical factors. This form, which is available for all ratings, lists all the military and all the professional practical factors. Whenever a person demonstrates his ability to perform a practical factor, appropriate entries must be made in the DATE and INITIALS columns. As a PO1 or CPO, you will often be required to check the practical factor performance of lower rated personnel and to report the results to your supervising officer.

As changes are made periodically to the Quals Manual, new forms of NavPers 760 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes to the Quals Manual.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	†E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service— or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6.	48 mos. as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3, AME 3, HM 3			Class B for AGCA, MUCA, MNCA.	Must be permanent appointment.	
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS	Locally prepared tests.		Navy-wide examinations required for all PO advancements.				Navy-wide, selection board, and physical.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		
	TARS attached to the air program are advanced to fill vacancies and must be approved by CNARESTRA.							

* All advancements require commanding officer's recommendation.

† 2 years obligated service required.

Figure 1-1. —Active duty advancement requirements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
	FOR THESE DRILLS PER YEAR								
TOTAL TIME IN GRADE	48 24 NON- DRILLING	6 mos. 9 mos. 12 mos.	6 mos. 9 mos. 24 mos.	15 mos. 15 mos. 24 mos.	18 mos. 18 mos. 36 mos.	24 mos. 24 mos. 48 mos.	36 mos. 36 mos. 48 mos.	48 mos. 48 mos.	24 mos. 24 mos.
DRILLS ATTENDED IN GRADE †	48 24	18 16	18 16	45 27	54 32	72 42	108 64	144 85	72 32
TOTAL TRAINING DUTY IN GRADE †	48 24 NON- DRILLING	14 days 14 days None	14 days 14 days None	14 days 14 days 14 days	14 days 14 days 14 days	28 days 28 days 28 days	42 days 42 days 28 days	56 days 56 days	28 days 28 days
PERFORMANCE TESTS					Specified ratings must complete applicable performance tests before taking examination.				
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 760, must be completed for all advancements.							
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIRE- MENTS)		Completion of applicable course or courses must be entered in service record.							
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.						Standard EXAM, Selection Board, and Physical.	
AUTHORIZATION		District commandant or CNARESTRA					Bureau of Naval Personnel		

* Recommendation by commanding officer required for all advancements.

† Active duty periods may be substituted for drills and training duty.

Figure 1-2.—Inactive duty advancement requirements.

The Record of Practical Factors also provides space for recording demonstrated proficiency or skills which are within the general scope of the rating but which are not identified as minimum qualifications for advancement. Keep this in mind when you are training and supervising other personnel. If a person demonstrates proficiency in some skill which is not listed in the quals but which is within the general scope of the rating, report this fact to the supervising officer so that an appropriate entry can be made in the Record of Practical Factors.

When you are transferred, the Record of Practical Factors should be forwarded with your service record to your next duty station. It is a good idea to check and be sure that this form is actually inserted in your service record before you are transferred. If the form is not in your record, you may be required to start all over again and requalify in practical factors that have already been checked off. You should also take some responsibility for helping lower rated personnel keep track of their practical factor records when they are transferred.

NavPers 10052

Training Publications for Advancement in Rating, NavPers 10052 (revised) is a very important publication for anyone preparing for advancement in rating. This publication lists required and recommended Navy Training Courses and other reference material to be used by personnel working for advancement in rating. NavPers 10052 is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the NavPers number. When using this publication, be SURE you have the most recent edition.

The required and recommended references are listed by rate level in NavPers 10052. It is important to remember that you are responsible for all references at lower rate levels, as well as those listed for the rate to which you are seeking advancement.

Navy Training Courses that are marked with an asterisk (*) in NavPers 10052 are MANDATORY at the indicated rate levels. A mandatory training course may be completed by (1) passing the appropriate Enlisted Correspondence Course that is based on the mandatory training course; (2) passing locally prepared tests based on the

information given in the mandatory training course; or (3) in some cases, successfully completing an appropriate Navy school.

When training personnel for advancement in rating, do not overlook the section of NavPers 10052 which lists the required and recommended references relating to the military requirements for advancement. Personnel of all ratings must complete the mandatory military requirements training course for the appropriate rate level before they can be eligible to advance in rating. Also, make sure that personnel working for advancement study the references which are listed as recommended but not mandatory in NavPers 10052. It is important to remember that ALL references listed in NavPers 10052 may be used as source material for the written examinations, at the appropriate rate levels.

Navy Training Courses

There are two general types of Navy Training Courses. RATING COURSES (such as this one) are prepared for most enlisted ratings. A rating training course gives information that is directly related to the professional qualifications of ONE rating. SUBJECT MATTER COURSES or BASIC COURSES give information that applies to more than one rating.

Navy Training Courses are revised from time to time to bring them up to date. The revision of a Navy Training Course is identified by a letter following the NavPers number. You can tell whether a Navy Training Course is the latest edition by checking the NavPers number (and the letter following the number) in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061.

Navy Training Courses are designed for the special purpose of helping naval personnel prepare for advancement in rating. By this time, you have probably developed your own way of studying these courses. Some of the personnel you train, however, may need guidance in the use of Navy Training Courses. Although there is no single "best" way to study a training course, the following suggestions have proved useful for many people.

1. Study the military requirements and the professional qualifications for your rating before you study the training course, and refer to the quals frequently as you study. Remember, you are studying the training course primarily to meet these quals.

2. Before you begin to study any part of the training course intensively, get acquainted with the entire book. Read the preface and the table of contents. Check through the index. Thumb through the book without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

3. Look at the training course in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the book.

4. When you have a general idea of what is in the training course and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit—it may be a chapter, a section of a chapter, or a subsection. The amount of material you can cover at one time will vary. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more studytime.

5. In studying each unit, write down questions as they occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

6. As you study, relate the information in the training course to the knowledge you already have. When you read about a process, a skill, or a situation, ask yourself some questions. Does this information tie in with past experience? Or is this something new and different? How does this information relate to the qualifications for advancement in rating?

7. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Without looking at the training courses, write down the main ideas you have gotten from studying this unit. Don't just quote the book. If you can't give these ideas in your own words, the chances are that you have not really mastered the information.

8. Use Enlisted Correspondence Courses whenever you can. The correspondence courses are based on Navy Training Courses or other appropriate texts. As mentioned before, completion of a mandatory Navy Training Course can be accomplished by passing an Enlisted Correspondence Course based on the training course. You will probably find it helpful to take other correspondence courses, as well as those

based on mandatory training courses. Taking a correspondence course helps you to master the information given in the training course, and also gives you an idea of how much you have learned.

INCREASED RESPONSIBILITIES

When you assumed the duties of a PO3, you began to accept a certain amount of responsibility for the work of others. With each advancement in rating, you accept an increasing responsibility in military matters and in matters relating to the professional work of your rating. When you advance to PO1 or CPO, you will find a noticeable increase in your responsibilities for leadership, supervision, training, working with others, and keeping up with new developments.

As your responsibilities increase, your ability to communicate clearly and effectively must also increase. The simplest and most direct means of communication is a common language. The basic requirement for effective communication is therefore a knowledge of your own language. Use correct language in speaking and in writing. Remember that the basic purpose of all communications is understanding. To lead, supervise, and train others, you must be able to speak and write in such a way that others can understand exactly what you mean.

Leadership and Supervision

As a PO1 or CPO, you will be regarded as a leader and supervisor. Both officers and enlisted personnel will expect you to translate the general orders given by officers into detailed, practical, on-the-job language that can be understood and followed by relatively inexperienced personnel. In dealing with your juniors, it is up to you to see that they perform their jobs correctly. At the same time, you must be able to explain to officers any important problems or needs of enlisted personnel. In all military and professional matters, your responsibilities will extend both upward and downward.

Along with your increased responsibilities, you will also have increased authority. Officers and petty officers have **POSITIONAL** authority—that is, their authority over others lies in their positions. If your CO is relieved, for example, he no longer has the degree of authority over you that he had while he was your

CO, although he still retains the military authority that all seniors have over subordinates. As a PO1, you will have some degree of positional authority; as a CPO, you will have even more. When exercising your authority, remember that it is positional—it is the rate you have, rather than the person you are, that gives you this authority.

Training

As a PO1 or CPO, you will have regular and continuing responsibilities for training others. Even if you are lucky enough to have a group of subordinates who are all highly skilled and well trained, you will still find that training is necessary. For example, you will always be responsible for training lower rated personnel for advancement in rating. Also, some of your best workers may be transferred; and inexperienced or poorly trained personnel may be assigned to you. Or a particular job may call for skills that none of your personnel have. These and similar problems require that you be a training specialist—one who can conduct formal and informal training programs to qualify personnel for advancement in rating, and one who can train individuals and groups in the effective execution of assigned tasks.

In using this training course, study the information from two points of view. First, what do you yourself need to learn from it? And second, how would you go about teaching this information to others?

Training goes on all the time. Every time a person does a particular piece of work, some learning is taking place. As a supervisor and as a training expert, one of your biggest jobs is to see that your personnel learn the RIGHT things about each job so that they will not form bad work habits. An error that is repeated a few times is well on its way to becoming a bad habit. You will have to learn the difference between oversupervising and not supervising enough. No one can do his best work with a supervisor constantly supervising. On the other hand, you cannot turn an entire job over to an inexperienced person and expect him to do it correctly without any help or supervision.

In training lower rated personnel, emphasize the importance of learning and using correct terminology. A command of the technical language of your rating enables you to receive and convey information accurately and to exchange ideas with others. A person who does

not understand the precise meaning of terms used in connection with the work of his rating is definitely at a disadvantage when he tries to read official publications relating to his work. He is also at a great disadvantage when he takes the examinations for advancement in rating. To train others in the correct use of technical terms, you will need to be very careful in your own use of words. Use correct terminology and insist that personnel you are supervising use it too.

You will find the Record of Practical Factors, NavPers 760, a useful guide in planning and carrying out training programs. From this record, you can tell which practical factors have been checked off and which ones have not yet been done. Use this information to plan a training program that will fit the needs of the personnel you are training.

On-the-job training is usually controlled through daily and weekly work assignments. When you are working on a tight schedule, you will generally want to assign each person to the part of the job that you know he can do best. In the long run, however, you will gain more by assigning personnel to a variety of jobs so that each person can acquire broad experience. By giving people a chance to do carefully supervised work in areas in which they are relatively inexperienced, you will increase the range of skills of each person and thus improve the flexibility of your working group.

CROSS-TRAINING—that is, preparing men in service ratings for advancement to the general rating—is an important part of the senior petty officers' training job. As noted before, the FTG1 cannot advance to FTC without learning the duties of the FTM. Similarly, the FTM1 must learn the duties of the FTG before he can advance to FTC.

The first step in setting up a program of cross-training is to review the qualifications. This will show that most of the quals are common for FTGs and FTMs at the 3rd and 2nd class levels. Exceptions are: the FTG must know lead computing sights, rangefinders, and information on the dual purpose battery. The FTM must know information about the missile fire control systems and the missile launchers. Therefore, cross-training must include missile information for the FTG, and rangefinder and dual purpose battery information for the FTM. Much of the information contained in this training manual will aid in the cross-training of

both the FTMs and the FTGs. Other sources of cross-training information are the training manuals for FT3 and FT2.

Working With Others

As you advance to PO1 or CPO, you will find that many of your plans and decisions affect a large number of people, some of whom are not even in your own rating. It becomes increasingly important, therefore, for you to understand the duties and the responsibilities of personnel in other ratings. Every petty officer in the Navy is a technical specialist in his own field. Learn as much as you can about the work of other ratings, and plan your own work so that it will fit into the overall mission of the organization.

Keeping Up With New Developments

Practically everything in the Navy—policies, procedures, publications, equipment, systems—is subject to change and development. As a PO1 or CPO, you must keep yourself informed about changes and new developments that affect you or your work in any way.

Some changes will be called directly to your attention, but others you will have to look for. Try to develop a special kind of alertness for new information. When you hear about anything new in the Navy, find out whether there is any way in which it might affect the work of your rating. If so, find out more about it.

SOURCES OF INFORMATION

As a PO1 or CPO, you must have an extensive knowledge of the references to consult for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the professional qualifications of your rating.

Some of the publications mentioned here are subject to change or revision from time to time—some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, make sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made.

The most widely used sources of information for the Fire Control Technician rating are the Ordnance Pamphlets (OPs) and the Ordnance Datas (ODs) published for all fire control equipments. The index for these publications is OP O.

Training films available to the Fire Control Technician are also a valuable source of supplementary information on many technical subjects. A selected list of training films that may be useful to you is given in Appendix I of this course. Other films that may be of interest are listed in the United States Navy Film Catalog, NavPers 10000 (revised).

ADVANCEMENT OPPORTUNITIES FOR PETTY OFFICERS

Making chief is not the end of the line as far as advancement is concerned. Proficiency pay, advancement to E-8 and E-9, and advancement to commissioned officer status are among the opportunities that are available to qualified petty officers. These special paths of advancement are open to personnel who have demonstrated outstanding professional ability, the highest order of leadership and military responsibility, and unquestionable moral integrity.

PROFICIENCY PAY

The Career Compensation Act of 1949, as amended, provides for the award of proficiency pay to designated enlisted personnel who possess special proficiency in a military skill. Proficiency pay is given in addition to your regular pay and allowances and any special or incentive pay to which you are entitled. Enlisted personnel in pay grades E-4 through E-9 are eligible for proficiency pay. Proficiency pay is allocated by ratings and NECs, with most awards being given in the ratings and NECs which are designated as critical. The eligibility requirements for proficiency pay are subject to change. In general, however, you must be recommended by your commanding officer, have a certain length of time on continuous active duty, and be career designated.

ADVANCEMENT TO E-8 AND E-9

Chief petty officers may qualify for the advanced grades E-8 and E-9 which are now provided in the enlisted pay structure. These

advanced grades provide for substantial increases in pay, together with increased responsibilities and additional prestige. The requirements for advancement to E-8 and E-9 are subject to change, but in general include a certain length of time in grade, a certain length of time in the naval service, a recommendation by the commanding officer, and a sufficiently high mark on the servicewide examination. The final selection for E-8 and E-9 is made by a regularly convened selection board.

Examination Subjects.—The examinations for pay grades E-8 and E-9 are divided into three sections: professional knowledge, supervisory knowledge, and common knowledge. The professional knowledge section is designed to measure, at an advanced level, a candidate's knowledge of his particular rating. Personnel who prepare these questions are guided by the Manual of Qualifications for Advancement in Rating and the related bibliography in Training Publications for Advancement in Rating. Pertinent publications from among those listed in the military requirements section of NavPers 10052 are used as sources of the supervisory knowledge section. The common knowledge section contains questions designed to test the candidate's arithmetical, mechanical, and verbal reasoning capabilities. Questions for this section are drawn from basic mathematics, physics, and vocabulary development texts.

Sources of Information.—In addition to the titles listed above, the following publications, distributed to Navy libraries and Educational Services offices, will assist the candidate for E-8 and E-9 in preparing for the examinations: College Entrance Examinations Study Material

(limited distribution); High School Subjects Self Taught Book (Navy-wide distribution); Basic Mathematics (Navy-wide distribution); Mathematics Review (Navy-wide distribution); popular texts on psychology (Navy-wide distribution); various USAFI texts (Navy-wide distribution); vocabulary development books (limited distribution).

ADVANCEMENT TO COMMISSIONED OFFICER

The Limited Duty Officer (Temporary) Program provides a path of advancement to commissioned officer status for outstanding petty officers of the Regular Navy. LDOs are limited, in their duty, to the broad technical fields associated with their former rating.

Education, length of service, and maximum age limits are usually specified in the requirements for advancement to LDO. However, these requirements vary according to circumstances, and the program is in a period of transition. If you are interested in advancing to LDO, ask your division officer for the latest requirements that apply to your particular case.

Another path of advancement to commissioned officer status is provided by the Integration Program. Enlisted personnel possessing the required qualifications may be appointed under this program to the grade of ensign in the Line, Supply, or Civil Engineer Corps of the Regular Navy. Education, length of service, and maximum age limits are included in the requirements for eligibility under this program. Eligibility requirements for this program, as well as for the other programs discussed here, are subject to change.

CHAPTER 2

BALLISTIC CALCULATIONS

The science of ballistics encompasses all the factors that affect the trajectory of a projectile. Ballistic data for a particular gun-projectile-velocity combination are obtained by experimental firings at the Naval Proving Grounds. Measurements are made of the trajectory, and the characteristics of the entire trajectory are computed. Standard conditions are established for the firings. The standard conditions are a base with which other firing conditions are compared. The ballistic data and standard ballistic conditions are promulgated to the fleet in range tables.

Fire control computers use the same ballistic data to predict a projectile's trajectory and to solve for the correct position of the line of fire. Thus the range table data for standard conditions are designed into the computer. But standard conditions are hard to come by at sea. In this section we will discuss the corrections you must calculate for deviations from standard conditions. Each factor is taken up separately, and later a procedure is established for practical calculation of the initial ballistic corrections.

Exactly what goes into the initial ballistic corrections depends on the fire control system. The method of inserting the corrections also varies with the different systems. Where it is practicable to do so, we will explain these differences. The ballistic corrections can be grouped into three general categories:

1. Initial Velocity Correction
2. Range Spot
3. Deflection Spot

INITIAL VELOCITY

Fire control computers are normally designed to use the nominal velocity of the gun. (Some computers, such as the Mk 1A, are designed to use the gun's expected average lifetime velocity.) Nominal velocity is the designed

velocity of a new gun, using a standard powder charge and a specific type of projectile. Initial velocity is the actual muzzle velocity of the projectile. The principal factors that affect the initial velocity with a particular gun and projectile are gun erosion and powder charge. (We will assume that the projectile is of standard weight and shape.)

EROSION

Gun erosion is the enlargement of the gun's bore and chamber. The chamber is sealed at the origin of the bore (fig. 2-1) by the projectile. The powder charge burns in the chamber and produces gas pressure which forces the projectile through the bore. Erosion increases the chamber's volume and reduces the effectiveness of the chamber's projectile seal. The net result of erosion is a reduction in the working pressure acting on the base of the projectile, and therefore a lower initial velocity.

There are three methods to determine the amount of gun erosion—(1) star gage measurement, (2) erosion gage, and (3) equivalent service round count. A star gage is a specialized instrument similar in function to an inside micrometer. The star gage measures the enlargement of the bore at prescribed positions along the barrel. Each time a barrel is star-gaged, the readings along with the total number of rounds fired and the number of rounds fired between star-gaging, are reported to BuWeps. In the Bureau, rounds fired versus wear is computed for each type gun. The result of this computation is a table of wear versus rounds fired (table 2-1); this table is supplied with the range tables. The star gage readings taken at the origin of the bore are used in the computation of initial velocity. Star gage measurements are taken by tender or Navy yard personnel.

The erosion gage does not measure the enlargement at the origin of the bore directly. It

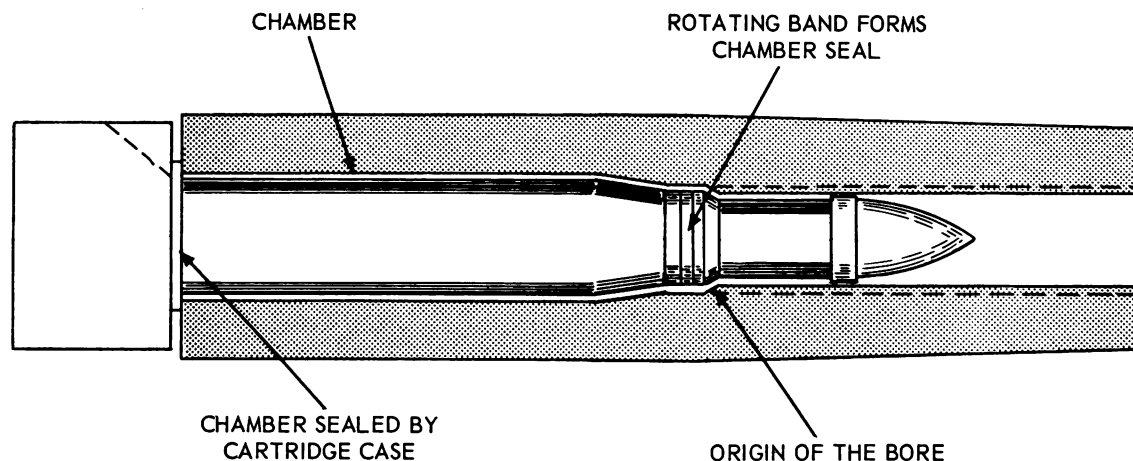


Figure 2-1. —Gun chamber and projectile seal.

84.235

measures the progress of erosion down the bore, which in most guns correlates closely with enlargement at the origin of the bore. (There are some exceptions to this, which are noted in the range table.) Erosion gage readings are taken by the ship's Gunner's Mates after a significant number of rounds have been fired, or prior to a scheduled shoot.

The equivalent service round (ESR) method to determine erosion is to keep a count of the rounds fired through each barrel. Erosion is approximately proportional to the number of rounds fired through the bore. But the amount of erosion varies with many factors, such as condition of gun wear, rapidity of fire, and powder charge. Thus a pseudo ESR is established. When the gun is star gaged, the ESR for that amount of erosion is determined from curves or tables in the range table. Subsequent service rounds fired are added to the ESR and become an up-to-date PESR. If a reduced charge is fired, a percentage or modifying factor equal to approximately the amount of erosion caused by the reduced charge is used. The percent is found in the range table. Later in this chapter we will compute an initial velocity and see how erosion data is converted to velocity loss data.

POWDER CHARGE

To determine the velocity loss due to erosion, the relationship between erosion and powder

charge is considered. A powder charge is designed to produce the nominal velocity in a new gun for a particular type projectile. The burning characteristics of different type powders vary; therefore the maximum pressure created in the gun chamber varies. This is compensated for by a change in the weight of a powder charge. The correct amount of powder in a charge of a particular powder index is determined by proof firing against a master powder charge of the same type. A master powder charge has a density and volume which will produce nominal velocity in a new gun. The type powder and the weight of the powder charge are considered when velocity loss due to erosion is calculated. The Gunner's Mate can tell you the type and weight of the powder charge which will be fired. Obviously, only the powder index to be fired is used to compute the initial velocity. It is interesting to note that some powder indexes produce an initial velocity in a new gun above nominal velocity. This is reflected in the range tables.

POWDER TEMPERATURE.—Powder temperature affects the burning rate and hence the maximum pressure created in the gun chamber. A standard powder temperature of 90° F has been arbitrarily established. A decrease in powder temperature reduces the burning rate and results in a lower initial velocity. This is normally the case aboard ship. Powder temperature is obtained from the magazine temperatures, which are taken daily. The residual

Table 2-1.—5"/38 Caliber guns Mk. 12 Mod 1.

BORE ENLARGEMENT AT ORIGIN vs EQUIVALENT SERVICE ROUNDS										
ESR	0	10	20	30	40	50	60	70	80	90
0	.000	.001	.001	.002	.002	.003	.004	.005	.006	.007
100	.008	.009	.011	.012	.013	.015	.016	.018	.020	.022
200	.024	.027	.029	.032	.035	.037	.040	.042	.044	.046
300	.048	.050	.052	.054	.055	.057	.059	.060	.062	.064
400	.065	.067	.068	.069	.071	.072	.073	.075	.076	.077
500	.078	.079	.081	.082	.083	.084	.085	.086	.087	.088
600	.089	.090	.091	.092	.093	.094	.095	.096	.096	.097
700	.098	.099	.100	.101	.101	.102	.103	.104	.105	.105
800	.106	.107	.108	.108	.109	.110	.110	.111	.112	.112
900	.113	.114	.114	.115	.116	.116	.117	.117	.118	.119
1000	.119	.120	.120	.121	.122	.122	.123	.123	.124	.124
1100	.125	.125	.126	.127	.127	.128	.128	.129	.129	.130
1200	.130	.131	.131	.132	.132	.133	.133	.133	.134	.134
1300	.135	.135	.136	.136	.137	.137	.138	.138	.138	.139
1400	.139	.140	.140	.140	.141	.141	.142	.142	.143	.143
1500	.143	.144	.144	.144	.145	.145	.146	.146	.146	.147
1600	.147	.147	.148	.148	.149	.149	.149	.150	.150	.150
1700	.151	.151	.151	.152	.152	.152	.153	.153	.153	.154
1800	.154	.154	.155	.155	.155	.156	.156	.156	.157	.157
1900	.157	.158	.158	.158	.159	.159	.159	.159	.160	.160
2000	.160	.161	.161	.161	.162	.162	.162	.162	.163	.163
2100	.163	.163	.164	.164	.164	.165	.165	.165	.165	.166
2200	.166	.166	.167	.167	.167	.167	.168	.168	.168	.168
2300	.169	.169	.169	.169	.170	.170	.170	.170	.171	.171
2400	.171	.171	.172	.172	.172	.172	.173	.173	.173	.173
2500	.174	.174	.174	.174	.174	.175	.175	.175	.175	.176
2600	.176	.176	.176	.177	.177	.177	.177	.177	.178	.178
2700	.178	.178	.179	.179	.179	.179	.179	.180	.180	.180
2800	.180	.180	.181	.181	.181	.181	.182	.182	.182	.182
2900	.182	.183	.183	.183	.183	.183	.184	.184	.184	.184
3000	.184	.185	.185	.185	.185	.185	.186	.186	.186	.186
3100	.186	.186	.187	.187	.187	.187	.187	.188	.188	.188
3200	.188	.188	.189	.189	.189	.189	.189	.189	.190	.190
3300	.190	.190	.190	.191	.191	.191	.191	.191	.191	.192
3400	.192	.192	.192	.192	.192	.193	.193	.193	.193	.193
3500	.193	.194	.194	.194	.194	.194	.194	.195	.195	.195
3600	.195	.195	.195	.196	.196	.196	.196	.196	.196	.197
3700	.197	.197	.197	.197	.197	.198	.198	.198	.198	.198
3800	.198	.198	.199	.199	.199	.199	.199	.199	.200	.200
3900	.200	.200	.200	.200	.200	.201	.201	.201	.201	.201
4000	.201	.202	.202	.202	.202	.202	.202	.202	.203	.203
4100	.203	.203	.203	.203	.203	.204	.204	.204	.204	.204
4200	.204	.204	.205	.205	.205	.205	.205	.205	.205	.206
4300	.206	.206	.206	.206	.206	.206	.206	.207	.207	.207
4400	.207	.207	.207	.207	.208	.208	.208	.208	.208	.208
4500	.208	.208	.209	.209	.209	.209	.209	.209	.209	.210
4600	.210	.210	.210	.210	.210	.210	.210	.211	.211	.211
4700	.211	.211	.211	.211	.211	.212	.212	.212	.212	.212
4800	.212	.212	.212	.213	.213	.213	.213	.213	.213	.213
4900	.213	.213	.214	.214	.214	.214	.214	.214	.214	.214
5000	.215	.215	.215	.215	.215	.215	.215	.215	.216	.216
5100	.216	.216	.216	.216	.216	.216	.216	.217	.217	.217
5200	.217	.217	.217	.217	.217	.217	.218	.218	.218	.218
5300	.218	.218	.218	.218	.218	.219	.219	.219	.219	.219
5400	.219	.219	.219	.219	.220	.220	.220	.220	.220	.220
5500	.220	.220	.220	.221	.221	.221	.221	.221	.221	.221
5600	.221	.221	.221	.222	.222	.222	.222	.222	.222	.222
5700	.222	.222	.223	.223	.223	.223	.223	.223	.223	.223
5800	.223	.223	.224	.224	.224	.224	.224	.224	.224	.224
5900	.224	.224	.225	.225	.225	.225	.225	.225	.225	.225

Bore Enlargement at Origin in inches

powder temperature is considered to be equal to the average of three days magazine temperatures. Naturally, you would use only the temperature of compartments which contain powder that will be fired. The change in velocity for a 1-degree change in powder temperature is calculated by using a coefficient given in the range table.

INITIAL VELOCITY INPUT

In some turrets an initial velocity corrector is incorporated in the individual gun or turret elevation drive. In these batteries the least eroded gun or lowest average of the guns in an individual turret is used to compute the initial velocity used in the rangekeeper. The erosion of the other guns in the battery is compensated for by the initial velocity corrector in the gun drive. A significant variation in powder temperature between turrets is also compensated for at the gun's initial velocity corrector.

In batteries without initial velocity correctors in the gun drive, all the corrections to initial velocity are applied in the computer. Average powder temperature and gun erosion is used. The erosion of the gun barrels in a battery should be kept nearly equal. By firing the most rounds through the least eroded gun, the erosion differences between gun barrels is kept to a minimum.

INITIAL RANGE SPOT

Here we will discuss the effects on range of variation from standard conditions of the atmosphere, rotation of the earth, trunnion height, and earth's curvature. The other ballistic corrections in range are calculated by the computer.

ATMOSPHERIC DENSITY

The mere presence of the atmosphere, without any wind, has a retarding effect on the projectile. The air resistance slows down the projectile and consequently reduces range. The amount by which range is reduced depends on the projectile's velocity and the air density. We will assume that the initial velocity is known, and that the projectile's weight and shape are standard. Air density varies with temperature and pressure of the atmosphere. To simplify the density correction, a standard ballistic

density has been established for comparison with the actual density.

Air is more dense near the surface of the earth than at higher altitudes. Thus surface fire results in greater loss of range than similar fire at a higher altitude. The various densities encountered along the trajectory depend on maximum ordinate and the location of the target. In surface fire, the projectile passes through the various densities twice; while in AA fire it may pass through them only once.

For the purpose of density correction, we assume that the atmosphere is divided into layers. An average density is calculated for each layer. The ratio of the actual density to the standard density determines the amount of correction. The ratio is expressed in percent. Thus, if a layer's ballistic density is 105%, the atmosphere in that layer is 5% more dense than standard.

The length of time a projectile remains in a layer determines the proper emphasis of that layer in calculating the density correction. Each layer is assigned a weighting factor. The sum of the weighting factors used to calculate the density correction is 1.00. Thus, for example, if a projectile passes through three layers in a situation in which the first layer has twice the effect on the ballistic density as each of the other two layers, the weighting factors are 0.50 for the first layer and 0.25 for each of the other two layers. If the ballistic densities were 110% for the first layer, 108% for the second layer, and 104% for the third layer, the total ballistic density is

$$\begin{array}{rccccccc} (110 \times 0.50) & + & (108 \times 0.25) & + & (104 \times 0.25) & = & \\ 55 & & 27 & & 26 & & = 108\% \end{array}$$

Table 2-2 is from a 5"/38 range table. The zones and layers are in 2500-yard intervals. The zones represent the maximum ordinate of the trajectory, found in column 8 of the range table. The ballistic density of each layer is furnished by an aerological unit. The resultant ballistic density is calculated as shown in the preceding paragraph. The ballistic density correction is calculated using column 12 of the range table. This method of calculating ballistic density correction is more accurate than using the air density nomogram in the range table. The nomogram is used when only surface readings are available.

Table 2-2.—Density weighting factors for the 5-inch 38-caliber guns.

WIND WEIGHTING FACTORS FOR THE 5-INCH 38-CALIBER GUNS

Zone	Maximum Ordnate (feet)	Layer							
		1 (sfc to 2,500')	2 (2,500'- 5,000')	3 (5,000'- 7,500')	4 (7,500'- 10,000')	5 (10,000'- 12,500')	6 (12,500'- 15,000')	7 (15,000'- 17,500')	8 (17,500'- 20,000')
A	2,500	1.00							
B	5,000	.22	0.78						
C	7,500	.14	.21	0.65					
D	10,000	.10	.15	.20	0.55				
E	12,500	.09	.11	.14	.20	0.46			
F	15,000	.08	.10	.12	.13	.23	0.34		
G	17,500	.07	.08	.10	.12	.14	.23	0.26	
H	20,000	.06	.07	.09	.11	.12	.17	.17	0.21

ELASTICITY OF THE AIR

As the projectile travels through the atmosphere it "pushes" the air out of its path. As you know, the resistance of the air is proportional to its density. However, there is another property of air which acts to retard the projectile in flight. This property is the elasticity of the air; it requires an additional correction. The elasticity of the air increases as the temperature increases. A standard surface temperature of 59° F has been established. The change in range due to variations in temperature is tabulated in column 12A in table 2-3.

TRUNNION HEIGHT

The line of fire (LOF) is normally established by an offset from the line of sight (LOS). The vertical distance between the director (LOS) and the gun trunnions (LOF) is compensated for by vertical parallax. But when a stable element or stable vertical controls elevation, which is often the case in surface fire, elevation is measured with respect to a horizontal plane tangent to the earth's surface at own ship's position. The error in range due to trunnion height is illustrated in figure 2-2. The trunnion

height error is not compensated for in the computer's solution. Therefore, a correction is included in the initial range spot when the stabilizing unit controls elevation.

The mean trunnion height of a battery is used to calculate the trunnion height correction. Trunnion height is obtained from ship's drawings. Since the gun is above the horizontal plane, the range error is "Over." That is, the fall of shot is beyond the target. The correction is a drop spot. Trunnion height correction is usually combined with earth curvature correction.

EARTH CURVATURE

The computer solves the fire control problem with respect to the earth's surface, which is assumed to be a horizontal plane. Thus the computer's solution is based on an assumption that the earth is flat. Because the earth's surface is curved, the target is not in the horizontal plane which is tangent to the earth at own ship's position. The greater the range, the farther the target falls below the horizontal. If the elevation angle were set to hit a target at the measured range in the horizontal plane the projectile would fall beyond the target (fig. 2-3).

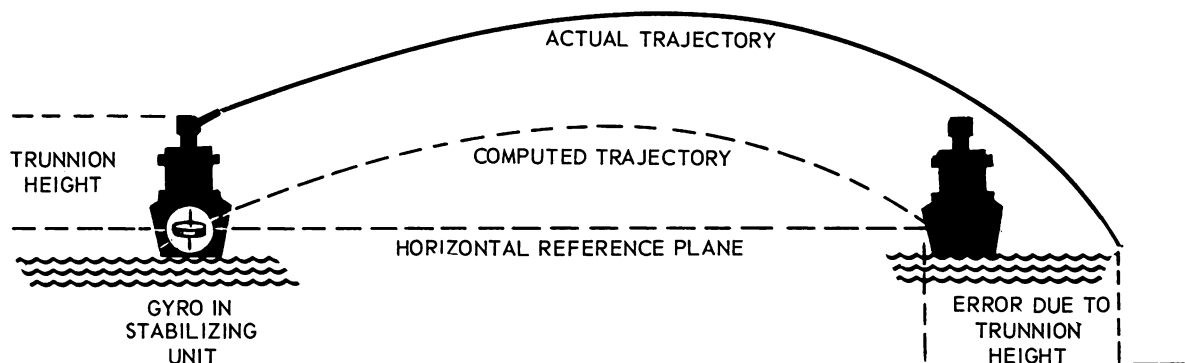
RANGE 1 YARDS	ANGLE OF ELEVATION 2 DEG. MIN.	CHANGE IN ANGLE OF ELEVATION FOR 100 YDS. INCREASE IN RANGE 2B MINUTES	ANGLE OF FALL 3 DEG. MIN.	TIME OF FLIGHT 4 SECONDS	STRIKING VELOCITY 5 FT./SEC.	DRIFT 6 YARDS	DANGER SPACE FOR A TARGET 20 FT. HIGH 7 YARDS	MAXIMUM ORDINATE 8 FEET
8000	7 11.6	431.6	13 12	15.83	1040	21.0	29	1033
8100	7 21.7	441.7	13 33	16.13	1035	22.0	28	1075
8200	7 32.0	452.0	13 54	16.43	1030	22.9	27	1118
8300	7 42.5	462.5	14 16	16.73	1026	23.9	26	1162
8400	7 53.1	473.1	14 37	17.03	1022	24.9	26	1207
8500	8 3.8	483.8	14 59	17.34	1018	26.0	25	1253
8600	8 14.7	494.7	15 20	17.64	1014	27.1	24	1301
8700	8 25.7	505.7	15 42	17.95	1010	28.2	24	1350
8800	8 36.9	516.9	16 4	18.26	1006	29.3	23	1400
8900	8 48.2	528.2	16 26	18.58	1002	30.5	23	1452
9000	8 59.7	539.7	16 49	18.89	999	31.7	22	1504
9100	9 11.3	551.3	17 11	19.21	995	33.0	22	1559
9200	9 23.1	563.1	17 34	19.52	992	34.3	21	1614
9300	9 35.0	575.0	17 56	19.84	989	35.6	21	1671
9400	9 47.0	587.0	18 19	20.17	985	37.0	20	1729
9500	9 59.2	599.2	18 42	20.49	982	38.4	20	1788
9600	10 11.6	611.6	19 5	20.82	979	39.8	19	1849
9700	10 24.0	624.0	19 29	21.15	976	41.3	19	1912
9800	10 36.7	636.7	19 52	21.48	973	42.9	18	1975
9900	10 49.5	649.5	20 16	21.81	970	44.4	18	2040
10000	11 2.4	662.4	20 39	22.14	968	46.0	18	2107
10100	11 15.5	675.5	21 3	22.48	965	47.7	17	2175
10200	11 28.7	688.7	21 27	22.82	962	49.4	17	2245
10300	11 42.1	702.1	21 51	23.16	960	51.1	17	2316
10400	11 55.6	715.6	22 15	23.50	958	52.9	16	2388
10500	12 9.3	729.3	22 40	23.85	955	54.7	16	2462
10600	12 23.1	743.1	23 4	24.19	953	56.6	16	2538
10700	12 37.1	757.1	23 29	24.54	951	58.6	15	2615
10800	12 51.3	771.3	23 53	24.89	949	60.5	15	2694
10900	13 5.6	785.6	24 18	25.25	947	62.6	15	2774
11000	13 20.0	800.0	24 43	25.60	945	64.6	14	2857
11100	13 34.6	814.6	25 8	25.96	943	66.8	14	2940
11200	13 49.4	829.4	25 34	26.32	941	68.9	14	3026
11300	14 4.4	844.4	25 59	26.69	939	71.2	14	3113
11400	14 19.5	859.5	26 24	27.05	938	73.5	13	3202

92.158

Table 2-3. —5-Inch 38-Caliber Gun I. V. 2500 F. S. 55. 18-pounds projectiles

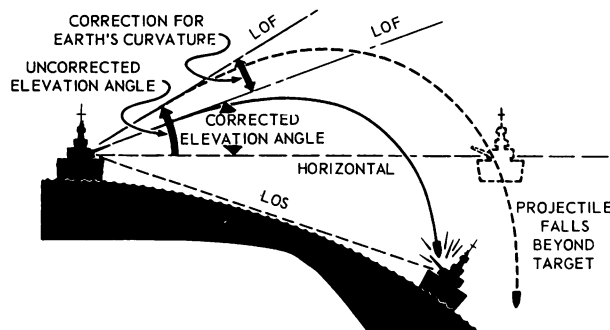
RANGE YARDS	CHANGE IN RANGE FOR				DEFLECTION FOR				CHANGE IN HEIGHT OF IMPACT FOR 100 YARDS CHANGE IN RANGE IN FEET										
	10 F.S. INCREASE IN INITIAL VELOCITY 10 YARDS	1 LB. DECREASE IN PRO- JECTILE WEIGHT 11 YARDS	10 PCT. DECREASE IN AIR DENSITY 12 YARDS	10 DEG. F. DECREASE IN AIR TEMPER- ATURE 12A YARDS	10-KNOT MOTION PERPENDICULAR TO PLANE OF FIRE														
					10 KNOT MOTION IN PLANE OF FIRE														
					WIND 13 YARDS	GUN 14 YARDS	TARGET 15 YARDS	WIND 16 YARDS		GUN 17 YARDS	TARGET 18 YARDS								
1 YARDS																			
8000	42	-11	374	17	48	41	89	34.6	54.5	89.1									
8100	42	-12	380	17	49	41	91	35.6	55.2	90.8									70
8200	42	-12	386	17	51	42	92	36.6	55.9	92.5									72
8300	43	-13	392	17	52	42	94	37.6	56.6	94.2									74
8400	43	-14	399	16	54	42	96	38.6	57.3	95.9									76
8500	43	-15	405	16	56	42	98	39.6	58.0	97.6									78
8600	43	-16	411	16	57	42	99	40.6	58.7	99.3									80
8700	44	-16	417	16	59	42	101	41.6	59.4	101.1									82
8800	44	-17	423	15	60	42	103	42.7	60.1	102.8									84
8900	44	-18	429	15	62	42	105	43.7	60.8	104.6									86
9000	44	-19	435	15	64	42	106	44.8	61.6	106.3									88
9100	45	-19	441	14	66	43	108	45.9	62.3	108.1									90
9200	45	-20	447	14	67	43	110	46.9	63.0	109.9									92
9300	45	-21	452	14	69	43	112	48.0	63.7	111.7									94
9400	45	-22	458	13	71	43	114	49.1	64.4	113.5									96
9500	45	-22	464	13	73	43	115	50.2	65.2	115.4									98
9600	46	-23	470	13	74	43	117	51.3	65.9	117.2									100
9700	46	-24	476	12	76	43	119	52.4	66.6	119.0									102
9800	46	-25	481	12	78	43	121	53.6	67.4	120.9									104
9900	46	-25	487	11	80	43	123	54.7	68.1	122.8									106
10000	47	-26	493	11	82	43	125	55.8	68.8	124.7									108
10100	47	-27	499	10	84	43	127	57.0	69.6	126.6									110
10200	47	-28	505	10	85	43	128	58.1	70.3	128.5									112
10300	47	-28	510	9	87	43	130	59.3	71.1	130.4									114
10400	47	-29	516	9	89	43	132	60.5	71.8	132.3									116
10500	48	-30	522	8	91	43	134	61.7	72.6	134.2									118
10600	48	-31	527	8	93	43	136	62.9	73.3	136.2									120
10700	48	-31	533	7	95	43	138	64.1	74.1	138.2									122
10800	48	-32	539	7	97	43	140	65.3	74.8	140.1									124
10900	48	-33	545	6	99	43	142	66.5	75.6	142.1									126
11000	49	-34	551	6	101	43	144	67.8	76.4	144.1									128
11100	49	-34	557	5	103	43	146	69.0	77.1	146.2									130
11200	49	-35	562	5	105	43	148	70.3	77.9	148.2									132
11300	49	-36	568	4	107	43	150	71.5	78.7	150.2									134
11400	49	-37	574	4	109	43	152	72.8	79.5	152.3									136

Table 2-3. —5-Inch 38-Caliber Gun I. V. 2500 F.S. 55. 18-pounds projectiles—Continued.



92.1

Figure 2-2.—Range error due to trunnion height.



92.2

Figure 2-3.—How earth's curvature reduces elevation angle.

This correction is small for short range fire, but becomes appreciable as range increases. A tabulated list of earth's curvature in feet versus range is given in BuOrd Circular Letter No. F8-43. Table 2-4 is the table from that letter.

Since both trunnion height and earth curvature affect range in a similar manner, these corrections are usually calculated together. Column 19 of the table 2-3 is used.

ROTATION OF THE EARTH

The motion of the earth is imparted to the projectile. The angular velocity of the earth is constant. But the linear rate of earth's rotation varies as a function of latitude. If the target is to either the north or south of own

ship's position, the earth's rotation will create an error. The amount of this error is determined by the difference in latitude between own ship and the target, and by the time the difference in linear rates of earth's motion acts. The direction of the error is determined by the true bearing of the line of fire. A correction is made for the error introduced by the earth's rotation only on guns larger than 5 inch. This error is negligible at relatively short range. The effect of earth's rotation on the trajectory is given in the range table for guns above 5-inch.

ARBITRARY CORRECTION TO HIT

At this point in our ballistic calculations we have taken into consideration all the ballistic factors which affect range. These include initial velocity and range corrections. But after all errors which can be accounted for are eliminated, there will probably remain an error in the fall of shot for which no cause is known. If the error is consistent, a correction called the Arbitrary Correction To Hit (ACTH) is applied. An ACTH is obtained from post-firing analysis, which is covered in the latter part of this chapter.

A correction for the first salvo only is sometimes used. A precise prediction of the initial velocity of the first round is hard to make. The amount of correction is derived from experience. The correction, sometimes called "cold gun," is applied for the first salvo and then removed.

Table 2-4. —Curvature of Earth, Feet.

R. yds.	0	100	200	300	400	500	600	700	800	900
1,000	0. 2	0. 3	0. 3	0. 4	0. 4	0. 5	0. 6	0. 6	0. 7	0. 8
2,000	. 9	. 9	1. 0	1. 1	1. 2	1. 3	1. 5	1. 6	1. 7	1. 8
3,000	1. 9	2. 1	2. 2	2. 3	2. 5	2. 6	2. 8	2. 9	3. 1	3. 3
4,000	3. 4	3. 6	3. 8	4. 0	4. 2	4. 4	4. 6	4. 8	5. 0	5. 2
5,000	5. 4	5. 6	5. 8	6. 1	6. 3	6. 5	6. 8	7. 0	7. 2	7. 5
6,000	7. 8	8. 0	8. 3	8. 5	8. 8	9. 1	9. 4	9. 7	10. 0	10. 3
7,000	10. 6	10. 9	11. 2	11. 5	11. 8	12. 1	12. 4	12. 8	13. 1	13. 4
8,000	13. 8	14. 1	14. 5	14. 8	15. 2	15. 6	15. 9	16. 3	16. 7	17. 1
9,000	17. 4	17. 8	18. 2	18. 6	19. 0	19. 4	19. 9	20. 3	20. 7	21. 1
10,000	21. 5	22	22	23	23	24	24	25	25	26
11,000	26	27	27	28	28	29	29	30	30	31
12,000	31	32	32	33	33	34	34	35	35	36
13,000	36	37	38	38	39	39	40	41	41	42
14,000	42	43	44	44	45	46	46	47	47	48
15,000	48	49	50	51	51	52	53	53	54	55
16,000	55	56	57	58	58	59	60	61	61	62
17,000	62	63	64	65	66	66	67	68	69	69
18,000	70	71	72	73	73	74	75	75	76	77
19,000	78	79	80	81	81	82	83	84	85	85
20,000	86	87	88	89	90	91	92	93	94	94
21,000	95	96	97	98	99	100	101	102	103	103
22,000	104	105	106	107	108	109	110	111	112	113
23,000	114	115	116	117	118	119	120	121	122	123
24,000	124	125	126	127	128	129	131	132	133	134
25,000	135	136	137	138	139	141	142	143	144	145
26,000	146	147	148	149	150	152	153	154	155	156
27,000	157	159	160	161	162	163	164	165	167	168
28,000	169	171	172	173	174	175	177	178	179	180
29,000	181	183	184	185	186	188	189	190	192	193
30,000	194	195	197	198	200	201	202	203	205	206
31,000	207	209	210	211	213	214	215	217	218	219
32,000	221	222	224	225	226	228	229	231	232	233
33,000	235	236	238	239	240	242	243	245	246	247
34,000	249	251	252	253	255	257	258	259	261	263
35,000	264	265	267	269	270	272	273	275	276	277
36,000	279	281	282	284	286	287	289	290	292	293
37,000	295	297	298	300	302	303	305	307	308	309
38,000	311	313	315	317	318	319	321	323	325	326
39,000	328	329	331	333	335	336	338	340	342	343
40,000	345									
R. yds.	0	100	200	300	400	500	600	700	800	900

INITIAL DEFLECTION SPOT

The initial deflection spot includes the corrections for the rotation of the earth and the ACTH. The correction in deflection to compensate for earth's rotation, like the range correction, is used in guns larger than 5 inch. Range tables give the deflection in yards, due to earth's rotation. Since the deflection spot is normally made in mils, yards are converted to mils. The ACTH in deflection is similar to that of range and is covered later in this chapter.

COMPUTATION OF THE INITIAL CORRECTIONS

A worksheet for the computation of initial ballistic corrections is shown in figure 2-4. The values in the sheet are representative, not taken from an actual firing. We will use these figures to solve a typical prefiring ballistic problem. The top line is for identification and the entries are self-explanatory. In the next line, the "Projectile" entry includes type of projectile, type of fuze, and projectile weight. If the weight of the projectile is not the same as listed in the range table, a correction is necessary. This correction is included in line 10, under other range errors. The "Charge" entry is either full/service or reduced/target. The "Range Table" entry is the OP used to compute ballistic corrections. The lower trajectory of the surface range table for the applicable gun-projectile-velocity combination is used. The procedure is the same regardless of the value. Thus, as we discuss the problem, you may substitute values from any available gunnery range table.

POWDER AND EROSION DATA

As item a in figure 2-4, enter the type powder, index number, and charge weight.

In item b, enter the nominal velocity. Its value is found in the erosion-data section of the range table. It should be noted that this entry is not always the standard velocity used to compute the range table. In some cases, such as the 5"/38 range table, the expected average velocity of the gun's lifetime is used.

In item c, enter the average residual temperature of the powder to be fired.

Item d, "Temperature Coefficient," is obtained from the erosion-data section of the range table. With the erosion in our example, the temperature coefficient is 1.2.

Space is provided in item e for the erosion data of the individual guns. In this example the right gun of three 5-inch twin mounts is used. Entries are made for the gun number, the "pseudo equivalent service rounds (PESR)" and bore enlargement or erosion-gage readings. The velocity loss due to erosion is determined by one of these values. When a gun is fired for the first time after star gage or bore erosion gage readings have been taken, the velocity loss is obtained directly from tables in the erosion data section of the range table. When star gage readings are available use the Velocity Versus Bore Enlargement at Origin And Charge Weight Table for the type powder to be fired (table 2-5). When bore erosion gage readings are available, use the velocity loss versus erosion gage reading and charge weight for the type powder to be fired. This table is similar in construction to table 2-5.

Suppose, however, the ship has fired several times since any erosion readings were taken on the gun barrel. In this event, the number of equivalent service rounds fired since the last star gage is determined. This number is added to the ESR determined with the star gage reading. This will give you the best estimate of the present PESR. We use this value to obtain bore enlargement at the origin from table 2-1. With bore enlargement we enter table 2-5 to obtain velocity loss due to erosion.

If the powder temperatures vary more than 2° F between guns, the powder temperatures are entered under the heading "Powder Temp. Corr." (fig. 2-4). The velocity loss for each gun is computed, using the formula in line 1 of the worksheet. If this is done, line 1 of the sheet is left blank. The velocity loss due to powder temperature is combined with the velocity loss due to bore enlargement. This sum is entered in the next column. The 5"/38 gun does not have an erosion corrector in its drive. Therefore, an average powder temperature is used in line 1 of the worksheet, and the average initial velocity loss (7 in this case) is used in line 2 of the worksheet.

ATMOSPHERIC CONDITIONS

Item f is the barometer reading in inches, and item g is the temperature from the dry bulb

Chapter 2—BALLISTIC CALCULATIONS

CONFIDENTIAL

(When filled in)

WORKSHEET FOR THE COMPUTATION OF
THE INITIAL BALLISTIC CORRECTION

BATTERY	5/38	EXERCISE	SAMPLE	DATE FIRED	10 Jan 1964
PROJECTILE	Mk35-Mk55-WT56	CHARGE	Full	RANGE TABLE	OP 551 (3rd Rev.)

POWDER AND EROSION DATA

a	Powder Index	SPDF	Charge WT	15.8	c	Average Powder Temp.	80°F
b	I.V. Erosion Data			2600 F.S.	d	Temperature coefficient	1.2 FS/°F
e	Gun	PESR	Bore Enlargement Inches	Gauge	Powder Temp. Corr.	Velocity Loss F.S.	Erosion Corrector Setting F.S.
	1R	500	.078	43.4	0	5	None
	2R	520	.081	43.6	0	7	Provided
	3R	530	.082	43.7	0	8	

ATMOSPHERIC CONDITIONS

ROTATION OF EARTH

f	Barometer	30.4 in	l	Latitude	No correction
g	Temperature	52° F	m	True Bearing	Needed for 5"
h	Ballistic Density	Not obtained			

TRUNNION AND CURVATURE DATA

RANGE TABLE DATA

TRUNNION AND CURVATURE DATA		A Range	10,000	
		B Column 12	493	
i	Average Trunnion Height	20.00 ft	C Column 12a	11
j	Curvature of Earth	21.5 ft	D Column 19	113
k	Sum (i) + (j)	41.5 ft	E Column 11	-26

COMPUTATION OF INITIAL VELOCITY

F.S.

1	Powder Temp., (d)x(90-c)	12
2	Erosion Lost and Index Correction	7
3	Total Velocity Loss, (1) (2)	19
4	Item b	2600
5	Expected I.V. (4) - (3)	2581

COMPUTATION OF RANGE CORRECTION

Yards
Over Short

6	Air Density, (100-m(B)) ÷ 10		210
7	Air Temperature, (59-g) ÷ (C) ÷ 10	7.7	
8	Trunnion and Curvature, 100(k) ÷ (D)	37	
9	Rotation of Earth for (1), (m), and (A)		
10	Other range errors	21.3	
		Drop	Add
11	Sum, (6) through (10)		166
12	ACTH from previous practices		75
13	Correction for first salvo only		100
14	Total Correction (11) + (12) + (13)		319

COMPUTATION OF DEFLECTION CORR.

Yards
Right Left

15	Rotation of Earth for (1), (m), and (A)	X	X
16	Other deflection errors	X	X
		Mils Left Right	
17	(1000) (15+16) ÷ (A)	X	X
18	ACTH from previous practices		5
19	Total Correction (17) + (18)		5

Figure 2-4.—Worksheet for the computation of initial ballistic corrections.

Table 2-5. —Velocity Loss vs Bore Enlargement at Origin & Charge Weight.

SPDF and SPWF INDEXES

	Charge					Weight						
	15.0	15.2	15.4	15.6	15.8	16.0	16.2	16.4	16.6	16.8	17.0	
0	-35	-35	-35	-35	-35	-35	-35	-35	-35	-35	-35	
2	-37	-37	-37	-37	-37	-37	-37	-37	-37	-37	-37	
4	-39	-39	-39	-39	-39	-39	-39	-39	-39	-40	-40	
6	-40	-40	-40	-40	-40	-40	-40	-40	-40	-41	-41	
8	-40	-40	-40	-40	-41	-41	-41	-41	-41	-42	-42	
10	-41	-41	-41	-41	-42	-42	-42	-42	-42	-43	-43	
12	-41	-41	-41	-41	-42	-42	-42	-42	-42	-43	-43	
14	-41	-41	-41	-41	-42	-42	-42	-42	-42	-43	-43	
16	-40	-40	-40	-40	-41	-41	-41	-41	-42	-42	-42	
18	-40	-40	-40	-40	-41	-41	-41	-41	-41	-42	-42	
20	-39	-39	-39	-39	-40	-40	-40	-40	-40	-41	-41	
22	-39	-39	-39	-39	-40	-40	-40	-40	-40	-41	-41	
24	-38	-38	-38	-38	-38	-38	-38	-38	-38	-38	-38	
26	-37	-37	-37	-37	-37	-37	-37	-37	-37	-37	-37	
28	-37	-37	-37	-37	-37	-37	-37	-37	-37	-37	-37	
30	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	
32	-34	-34	-34	-34	-34	-34	-34	-34	-34	-34	-34	
34	-33	-33	-33	-33	-33	-33	-33	-33	-33	-33	-33	
36	-32	-32	-32	-32	-32	-32	-32	-32	-32	-32	-32	
38	-30	-30	-30	-30	-30	-30	-30	-30	-30	-29	-29	
40	-29	-29	-29	-29	-28	-28	-28	-28	-27	-27	-27	
42	-26	-27	-27	-27	-26	-26	-26	-26	-26	-25	-25	
44	-25	-25	-25	-25	-25	-24	-24	-24	-24	-23	-23	
46	-23	-24	-24	-23	-23	-23	-22	-22	-22	-21	-21	
48	-22	-22	-22	-22	-21	-21	-20	-20	-20	-19	-19	
50	-20	-21	-20	-20	-19	-19	-19	-18	-18	-17	-17	
52	-18	-19	-19	-18	-18	-17	-17	-16	-16	-16	-15	
54	-17	-17	-17	-16	-16	-16	-15	-15	-14	-14	-13	
56	-16	-16	-15	-15	-14	-14	-13	-13	-12	-12	-11	
58	-14	-14	-14	-13	-13	-12	-11	-11	-10	-10	-9	
60	-13	-13	-12	-11	-11	-10	-10	-9	-8	-8	-7	
62	-11	-11	-10	-10	-9	-8	-8	-7	-6	-6	-5	
64	-9	-9	-9	-8	-7	-7	-6	-5	-4	-4	-3	
66	-8	-8	-7	-6	-6	-5	-4	-3	-3	-2	-1	
68	-6	-6	-5	-5	-4	-3	-2	-1	-1	0	1	
70	-5	-5	-4	-3	-2	-1	0	0	1	2	3	
72	-3	-3	-2	-1	0	0	1	2	3	4	5	
74	-1	-1	-1	0	1	2	3	4	5	6	7	
76	0	0	1	2	3	4	5	6	7	8	9	
78	1	2	3	4	5	6	7	8	9	10	11	
80	2	3	4	5	7	8	9	10	11	12	13	
82	4	5	6	7	8	9	10	12	13	14	15	
84	5	7	8	9	10	11	12	13	15	16	17	
86	7	8	9	11	12	13	14	15	17	18	19	
88	8	10	11	12	13	15	16	17	18	20	21	
90	9	11	13	14	15	17	18	19	20	22	23	
92	11	13	14	16	17	18	20	21	22	24	25	
94	13	15	16	17	19	20	21	23	24	26	27	
96	15	16	18	19	20	22	23	25	26	28	29	
98	16	18	19	21	22	24	25	27	28	29	31	
100	17	19	21	22	24	25	27	28	30	31	33	
102	19	21	23	24	26	27	29	30	32	33	35	
104	21	23	24	26	27	29	31	32	34	35	37	
106	23	24	26	27	29	31	32	34	36	37	39	
108	24	26	27	29	31	33	34	36	38	39	41	
110	25	27	29	31	33	34	36	38	39	41	43	

thermometer in degrees Fahrenheit. Both are surface readings taken from the ship's instruments located in the ship's bridge. Item h, "Ballistic Density," is left blank unless this information is available.

TRUNNION AND CURVATURE DATA

We will assume the exercise is a surface firing with the stable element controlling elevation. Thus trunnion height and earth curvature corrections are necessary. Item i is the average height of the gun trunnions above the waterline. Item j is the earth's curvature for the range listed in item A. Item k is the sum of items i and j.

ROTATION OF THE EARTH

This correction is omitted for guns of 5-inch and below.

RANGE TABLE DATA

The best estimate of firing range is entered as item A. Using this range, take items B, C, D, and E from the range table.

COMPUTATION OF INITIAL VELOCITY

We will first compute velocity loss. Line 1 is the error in I.V. due to a variation in powder temperature from 90° F. It should be noted that if the temperature is greater than 90° F, the sign is negative (-), even though an increase in range results. The reason for this is not obvious, but a study of line 1 in comparison with lines 2 and 3 will clarify it. Line 2 is always a velocity loss (since erosion never increases I.V.). The effect of a powder temperature above 90° F will reduce this loss, while a powder temperature below 90° F will increase the loss. Line 3, which is the algebraic sum of lines 1 and 2, will therefore be of the correct sign if powder temperature correction is treated as described above. Should line 3 come out with a minus sign, it would indicate a velocity gain. Such a case could occur with a new gun when firing powder from a magazine where the powder temperature was above 90° F. This will rarely happen.

Line 4 is the nominal velocity from item b. Line 5 is the expected I.V. which is found by subtracting the Total Velocity Loss (line 3) from the Nominal Velocity (line 4). This result

(line 5) is the expected initial velocity of the projectile, and is set into the computer.

COMPUTATION OF RANGE CORRECTION

To start with, we deal with the errors—that is, the difference between the expected impact point for standard conditions and the expected impact point for existing conditions. The entry in line 6 has been determined from the nomogram in the range table. When ballistic density (item h) is used, the formula in line 6 will give the proper value of range correction due to density. If item h is greater than 100%, the entry is made in the "Short" column; if less than 100%, the entry is made in the "Over" column. Line 7 is the range change due to variations of the air temperature from standard. If the air temperature is above standard, the entry is made in the Short column; if below standard, the entry is made in the Over column.

The trunnion height and curvature entry in line 8 is always "over." Column 19 of the range table (table 2-3) gives the change in height of impact due to a 100-yard change in range. These values assume the gun and target are in the horizontal plane. Trunnion height and earth's curvature are the amounts the problem deviates from the horizontal plane. Since the problem is concerned with total deviation from the horizontal, we can combine these factors. The formula in line 8 results in the number of yards by which range must be changed to compensate for total deviation.

No compensation is made for earth's rotation in the 5"/38 battery. Therefore line 9 is left blank. Line 10, "Other Range Errors," is provided for range errors which are normally not encountered. Under this heading in our example we have projectile weight. The range table is for a projectile weight of 55.18 pounds, and our projectile weighs 56 pounds. The formula used to calculate the compensation for the effect of a variation in projectile weight is:

$$\begin{aligned} \text{range table weight} - \text{actual weight} \times \text{column 11} &= \\ 55.18 - 56 \times -.26 &= \\ .82 \times 26 &= 21.3 \end{aligned}$$

Column 11 gives the effect on range due to a decrease in weight. Since in the example the projectile is heavier, range is increased. Projectiles heavier than standard will leave the gun at a lower initial velocity, which results in a decrease in range. But the heavier projectiles

have an increase in ballistic coefficient which results in an increase in range. At short ranges the change in initial velocity has the greatest effect, but at long ranges the ballistic coefficient has the greatest effect.

Line 11 is the algebraic sum of the range errors. Note that the column headings have been changed from "Over" to "Drop," and from "Short" to "Add." In this manner we are converting the errors to corrections. These are reciprocal quantities.

The ACTH in line 12 and the correction for first salvo only in line 13 are obtained from experience within the individual battery. The ACTH remains throughout the firing, but the value of line 13 is removed after the first salvo.

Line 14 is the algebraic sum of the range corrections. This value is set into the computer as a range spot. In AA fire the range correction is sometimes converted to an initial velocity correction. When this is done the first salvo correction is not included, and the trunnion height and earth curvature corrections are not needed. The formula to convert range correction to initial velocity correction is:

$$\frac{\text{Range correction} \times 10}{\text{Column 10}} = \text{Initial velocity correction}$$

COMPUTATION OF DEFLECTION CORRECTION

Line 15 is the error in deflection due to earth's rotation. Like range, it is used only in batteries larger than 5-inch. The error's value and sign are obtained from tables in the range table.

Line 16, "Other Deflection Errors," is provided for deflection errors which are normally not encountered.

The formula in line 17 is used to convert yards to mils. Deflection is normally spotted in mils. Note that the column headings have been changed from "Right" to "Left," and from "Left" to "Right." As in range, we are converting from the error to the correction. The ACTH in line 18 is obtained from previous shoots of the battery. Line 19 is the total deflection correction and is applied to the computer as a deflection spot.

POST-FIRING ANALYSIS

It has been said, "The best rangefinder is the gun." This implies that the effectiveness

of a fire control system is shown by the actual impact point of the projectile. Post-firing analysis concerns itself with a comparison between the observed impact point and the correct theoretical position of the impact point. From this comparison, consistent errors which cannot be accounted for are determined. An arbitrary correction to hit (ACTH) in range and deflection is computed from these errors. The best results are obtained when error-producing factors (such as relative motion and initial ballistic calculation) are held to a minimum. The ACTH is normally computed from a specially designed shoot. The shoot, normally a Z-24-G, is held under as nearly ideal conditions as possible. The battery was accurately aligned, and the fire control system was brought to peak performance.

A standard procedure and standard forms are used to determine the ACTH. The standard form is Gunnery Sheet #4 shown in figures 2-5 and 2-6. A worksheet (fig. 2-7) is used in conjunction with the finished smooth Sheet 4. Observers record the needed information available aboard ship for each salvo. The location of the impact point or mean point of impact is obtained from a spotting or photographic party. Spotting procedures are covered in a later chapter.

In the figures, a sample problem of a salvo from the right guns of the twin 5" mounts of a destroyer battery is shown. The values in the figures are representative but are not from an actual shoot.

WORKSHEET

A separate worksheet is used for each salvo. The worksheet is a complete picture of the conditions that existed at the instant the salvo was fired.

Range Table Data

In item A (fig. 2-7) enter the initial velocity for which the range table is computed. The 5" range table (OP 551 3rd Revision) is computed for 2500 foot-seconds.

In item B enter the gun's angle of elevation above the horizontal plane at the time of firing. When the stable element controls elevation, this value is obtained from sight angle. Since 2000 minutes represents zero sight angle, we have subtracted 2000 from the value of sight angle in the computer.

Chapter 2—BALLISTIC CALCULATIONS

GUNNERY SHEET 4
OPNAV FORM 3570-4 (Rev. 2-53)

CONFIDENTIAL
(When filled in)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (RANGE)

U.S.S.	EXERCISE	RUN	DATE
BATTERY	SAMPLE	Projectile	
5"/38	CHARGE (Full, reduced) Full	Range Table (Op No. 551 (3rd Rev.))	AND CHANGE NO.
POWDER INDEX	EROSION CURVES	NPG NO.	AND
SPDF	WT 15.8		

ITEM	SALVO NO	SALVO NO	SALVO NO	SALVO NO	SALVO NO	SALVO NO
(Tabulate range and change in range in yards)	1					
a. Number of guns	3					
b. Number of cold guns	0					
c. Guns fired	1R, 2R, 3R					
d. Gun range	10100					
e. Own ship's motion	+39					
f. True wind (upper air, surface)	-59					
g. Air density (upper air, surface)	-200					
h. Air temperature	+					
i. Rotation of earth	-					
j. Trunnion height and earth's curvature	+36					
k. Powder index						
l. Powder temperature	+381					
m. Erosion						
n. Sum of e through m	+204					
o. Expected range (d+n)	10304					
p. Navigational range at instant of firing	9950					
q. Target motion	-44					
r. Error of MPI	+140					
s. Actual range (p + q + r)	10044					
t. ACTH in range (o-s)	+360					

NOTES: c. Identify guns by turret or mount number and gun position, i.e., 1R; 2C; 3 all, etc.
d. Gun range is range table range corresponding to elevation of gun above horizontal plane.
e. Through m & q compute, using methods explained in range table, erosion curves & NAVPERS 16116, Naval Ordnance and Gunnery, page 271
f. & g. Cross out either upper air or surface as applicable.

63.40

Figure 2-5.—Gunnery Sheet 4—ACTH Range.

When the director controls elevation, sight angle is the angle between the LOS and the LOF. In this case trunnion height and earth curvature corrections are converted to minutes of arc and subtracted from sight angle. This brings the LOS into the horizontal plane. In batteries which have individual erosion correctors, the settings on the corrector affects gun elevation. The velocity loss in foot-seconds is converted to minutes of arc and subtracted from sight angle.

Item C is the range table value corresponding to item B. In the example, a range of 10,100 corresponds to an angle of elevation of 675.5 minutes above the horizontal plane.

Items D through N are taken directly from the range table, using the range in item C.

The remainder of the worksheet is used to compute the initial velocity, range, and deflection problems of the shoot. You are familiar

with such problems, so we will not discuss their solution here. However, here is a good place to practice working a typical problem. As you work the problem the following may possibly be new to you. The value in line 7 is used to compensate for an error in range. This error is caused by the difference between range table initial velocity, 2500 foot-seconds, and projectile's initial velocity 2581. The formula in line 8 calculates this range factor. The quantity "p" in the formula in line 17 is navigational range (best range to the target at the instant of firing) obtained from Sheet 4.

COMPUTATION OF ACTH IN RANGE

The first lines on Sheet 4 (fig. 2-5) are for identification purposes and in general are self-explanatory. However, the space labeled "RUN"

FIRE CONTROL TECHNICIAN 1 & C

GUNNERY SHEET 4
OPNAV FORM 3570-4 (Rev. 2-53) (BACK)

CONFIDENTIAL
(When filled in)

COMPUTATION OF ARBITRARY CORRECTION TO HIT (DEFLECTION)

ITEM (Tabulation range and change in range in yards)	SALVO NO 1	SALVO NO	SALVO NO	SALVO NO	SALVO NO	SALVO NO	SALVO NO
u. Deflection used (mils)	+3						
v. Drift (yds.) (right)	+47.7						
w. Own ship's motion (yds.)	+109						
x. Wind (yds.)	+40						
y. Rotation of earth (yds.)	---						
z. 1000 (v.+w.+x.+y) ÷ s. (mils)	+20						
aa. Expected deflection MPI (u.+z.) (mils)	+23						
bb. Target motion (mils)	+25						
cc. Error of MPI (mils)	-2						
dd. Actual deflection MPI (aa.-cc.) (mils)	+23						
ee. ACTH in deflection (aa.-dd) (mils)	0						

NOTES: v. through y and bb, refer to range table, erosion curves and NAVPERS 16116, Naval Ordnance & Gunnery
bb. is deviation for lateral motion of target (yds)
cc. is error of MPI from center of target (yds)

Figure 2-6. —Gunnery Sheet 4—ACTH Deflection.

63.40

is normally used to identify the projectile/fuze combination and the weight of the combination.

Item a, "Number of Guns," refers to the number of guns actually fired. If, for example, a 6-gun salvo was intended, but due to a casualty only five guns fired, the proper entry is 5.

In item b, "Number of Cold Guns," enter the number of guns firing their initial round since the barrel was last cleaned and oiled. We will assume that the guns had been fired just previously to this exercise. Therefore the entry is zero.

Item c, "Guns Fired," identifies guns by turret or mount number and position in the turret or mount. The right guns of mounts 1, 2, and 3 were fired in this hypothetical practice.

Items d, e, f, g, h, and j are obtained from the worksheet. When you transfer values from the worksheet, be sure the sign is carried with them. Item i is zero in the example, hence this correction is omitted for guns of 5-inch and smaller caliber.

The total for items k, l, and m is combined in the computations on the worksheet. Although the computed I.V. of 2581 foot-seconds would cause a decrease in range from values taken from a 2600 foot-second range table, it does cause an increase in the range values taken from the 2500 foot-second range table which is being used in computing values in the example. Therefore, the sign is PLUS for this entry of 381 yards.

Item o, the expected range is the gun range corrected for all known variations from standard range table conditions which affect the projectile in flight, plus trunnion height and earth's curvature. It should be noted that the target motion does not enter into this computation, because the value of expected range applies to the point of fall of the projectiles and is to be used for comparison with the actual range to the point of fall.

Chapter 2—BALLISTIC CALCULATIONS

CONFIDENTIAL
(When filled in)

WORKSHEET FOR PREPARING GUNNERY SHEET 4
(Use separate Worksheet for each Salvo)

Z	True Target Bearing At Instant of Firing	165°	RANGE TABLE DATA	
			A	Range Table I.V.
			B	Guns Elevation
			c	GUN Range (1)
			D	Column 10
			E	Column 12
			F	Column 12a
			G	Column 13
			H	Column 14
			I	Column 15
			J	Column 19
AA	True Course	265°	K	Column 6 (2)
BB	Speed	20	L	Column 16
CC	Acute Angle	80°	M	Column 17
DD	Cosine	.174	N	Column 18
EE	Sine	.985		
			ATMOSPHERIC CONDITIONS	
			O	Barometer
			P	Temperature
			Q	Ballistic Density
			POWDER AND EROSION DATA	
			R	I.V. (Erosion Data)
			S	Temperature Coefficient
			T	Average Powder Temperature
			U	Bore Enlargement - Inches
FF	True Course	300°	TRUNNION AND CURVATURE DATA	
GG	Velocity	10	V	Average Trunnion Height
HH	Acute Angle	45°	W	Curvature of Earth
II	Cosine	.707	x	Sum (V) + (W)
JJ	Sine	.707	COMPUTATION OF INITIAL VELOCITY	
			1	Powder Temp. Correction (S) x (90-T)
			2	Erosion Loss & Index Correction
			3	Total Velocity Loss (1) + (2)
			4	Item R
			5	Expected I.V. (4) - (3)
			6	Item A
			7	I.V. Difference (5) - (6)
			COMPUTATION IN RANGE	
KK	True Course	225°	8	I.V. Difference (7)x(D)+10
LL	Speed	18	9	Own Ship Motion (LL)x(NN)x(H)+10
MM	Acute Angle	60°	10	Wind (GG)x(II)x(G)+10
NN	Cosine	.500	11	Air Density (100-Q)x(E)+10
OO	Sine	.866	12	Air Temperature (59-P)x(F)+10
(1)	Enter in Sheet 4 as item d		13	Trunnion and Curvature 100(v)+J
(2)	Enter in Sheet 4 as item v		14	Target Motion (BB)x(DD)x(I)+10
(3)	Enter in Sheet 4 as total for items k, l and m		COMPUTATION IN DEFLECTION	
(4)	Enter in Sheet 4 as item e		15	Own Ship Motion (LL)x(OO)x(M)+10
(5)	Enter in Sheet 4 as item f		16	Wind (GG)x(JJ)x(L)+10
(6)	Enter in Sheet 4 as item g		17	Target Motion (100)x(BB)x(EE)x(N)+(P)+(14)
(7)	Enter in Sheet 4 as item h			
(8)	Enter in Sheet 4 as item j			
(9)	Enter in Sheet 4 as item q			
(10)	Enter in Sheet 4 as item w			
(11)	Enter in Sheet 4 as item x			
(12)	Enter in Sheet 4 as item bb			

Figure 2-7. —Worksheet for preparing Gunnery Sheet 4.

Item p is the navigational range at the instant of firing. The most accurate and carefully calibrated radar should be used to obtain this figure.

Item q is obtained from the worksheet, using care in selecting the proper sign. Since in the example the target is closing, the range will decrease during the time of flight of the projectile.

Item r, the error of MPI, represents the actual difference between the position of the target at the instant of the fall of the projectiles and the mean point of impact of the several shots. The precise definition of MPI, mean point of impact, and the method of computing it from the points of impact of the several individual shots, are discussed in a later chapter.

For this use in post-firing analysis, the best available data on the points of fall of individual projectiles should be used. When a camera party is available, these best data are obtained by triangulation of aerial photographs. OVERS carry the plus (+) sign; SHORTS, minus (-). An arbitrary value of +140 for error of MPI is used in figure 2-5.

Item s, it will be apparent by inspection, represents the actual range, to the point of fall, of the projectiles fired.

Item t, therefore represents the otherwise unaccounted-for errors, the average value of which is used as ACTH in range.

COMPUTATION OF ARBITRARY CORRECTION TO HIT (DEFLECTION)

Item u (fig. 2-6) is the difference between the midpoint of the deflection scale and the actual scale reading. It is the number of mils between the plane through the LOS and the plane

through the LOF at the instant the gun was fired. The sign is + if the scale reading is to the right of the midpoint and - if to the left. In the example the scale reading was 503.

Items v, w, and x—47.7, 109, and 40 yards, respectively in this example—are taken from the worksheet. The proper sign is important.

Item y is similar to item i and its value is zero in this example for the reason that was previously given.

Item z, it will be noted, includes a conversion from yards to mils at the actual range.

Item aa, the expected deflection, consists of the deflection used, corrected for drift and those variations from standard range table conditions which affect the projectile while it is in the air. This item serves the same purpose in deflection as item o in range.

Item bb is obtained from the worksheet.

Item cc is the error of the MPI in mils, obtained by photo triangulation or observation. If the MPI is right of the target, the sign is +, if left -. In the example, the error of the MPI was 2 mils left.

Item dd is the actual deflection of the MPI in mils. It is the perpendicular distance (converted to mils) from the vertical plane through the line of sight to the mean point of impact. This item is the deflection equivalent of item s above.

Item ee, the ACTH in deflection, is obtained by subtracting item aa from item dd. Like item t in range, it represents the errors otherwise unaccounted for. The ACTH in range and deflection represent the two values which are found through the processes of post-firing analysis.

CHAPTER 3

ANALOG COMPUTERS

INTRODUCTION

This chapter presents the basic concepts of the analog type fire control computer. The computer makes the necessary calculations to aim a weapon from the deck of a moving, pitching and rolling ship, so as to hit a moving target. To aim the weapon correctly under these conditions, many things must be considered simultaneously. At first it might seem that such an instrument would be far too complex for you to understand. This is not true. A computer is an assembly of basic computing elements, none of which are difficult to comprehend. Each element solves its own problem, which is a part of the fire control problem. A study of the fire control problem and the basic computing elements will lead to an understanding of the computer. To know the whole, you must know its integral parts. This is the approach taken to the study of the computer in this course.

Many references are made to material covered in previous courses. So before proceeding, we will note the related areas already covered. The basic elements of the fire control problem were emphasized in Fire Control Technician 3, NavPers 10173-A. This course also included an introduction to computing elements. In Fire Control Technician 2, NavPers 10174-A, one approach to the solution of the fire control problem was covered. The solution was tied to a mechanical computer. It was felt that mechanical units are more easily understood. The trend in computers, however, is toward electrical and electronic components.

electronic computing circuits or components. The physical values in these systems are measurable. This is a rather abstract idea, so we will illustrate it. As an example we will use the computation for future target height Rv_2 . The formula for Rv_2 is:

$$Rv_2 = R \sin E + T_2 \cdot DMv$$

Where:

R = present range

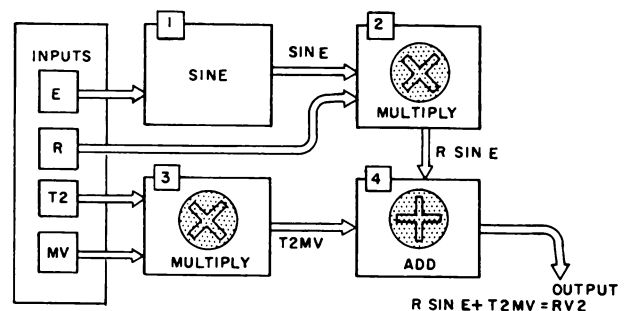
E = present elevation

T_2 = time of flight

DMv = linear rate at which target height is changing

Solving the formula requires four separate operations:

1. Find $\sin E$
2. Multiply $\sin E$ by R
3. Multiply T_2 by DMv
4. Add $R \sin E$ and $T_2 DMv$



92.5

Figure 3-1.—Mathematical operations.

PRINCIPLES OF ANALOG COMPUTERS

An analog computer simulates a mathematical problem in a physical system. In fire control computers the mathematical problem is duplicated using mechanical, electrical, and

In figure 3-1 these operations are shown in an arrangement similar to that found in a computer. The mathematical functions are shown in block form. By substituting computing elements, we can mechanize the formula. R and E are

measured by the director, and are known quantities. T_2 and DM_v are computed quantities which we will assume are correct, for they enter the formula with definite values. We will discuss the validity of this assumption later. Figure 3-2A, B, C, and D shows the mechanization of the formula in different types of systems.

Each element in the figure solves a discrete problem which is an integral part of the overall problem. There is practically no delay in an element arriving at an answer, once its inputs are set the answer is present as an output. To demonstrate this we will use one of the multiplying potentiometers in figure 3-2. The input values of R and $\sin E$ are represented by a voltage and an angle respectively. An infinite number of combinations of these values are possible, but they can be represented quickly and accurately in their analogous systems. As a target moves in or out along the range scale, its voltage representation follows it in a linear manner along the voltage scale. The voltage, within its limits of operation, is a continuous, uninterrupted representation of the numerical value of range. This voltage is applied directly to the multiplying potentiometer. As the target moves, elevation is also subject to change. This results in a changing value at E to the resolver in the figure. The resolver's output is a voltage directly proportional to $\sin E$. This voltage is applied to the servosystem. The servosystem's output is an angle directly proportional to $\sin E$, and is available almost instantaneously. This changing angle moves the wiper arm of the potentiometer. The potentiometer multiplies the input voltage by the angle on the wiper arm. The output voltage taken from the wiper arm is proportional to the product. Thus, although we have two dynamic input quantities, the answer is always available.

BASIC COMPUTING ELEMENTS

The preceding discussion shows how a computing network can be divided into easily understood computing elements. Unfortunately, a complete coverage of basic computing elements in this series of courses is impractical. However, there are OPs on basic elements, and computer OPs usually contain information on basic elements. Basic Electronics, NavPers 10087-A, also has some coverage.

SERVOSYSTEMS

A computing network is only as accurate as its information. Analog computers operate on

a continuous scale principle. To obtain smooth and accurate operation, the information flow is best controlled automatically by the computer itself. Normally the output power of a computing element is too small to do appreciable amounts of work. This power must be amplified to a level capable of doing the necessary work without loading down the computing element. To obtain the desired degree of accuracy and reliability, computers use high fidelity servosystems (servos). These servos have the following characteristics.

1. They are sensitive to small signals.
2. They have constant gain.
3. They are distortion free.

Computer servos are used in precision networks; special test sets and circuitry are usually furnished.

SCALE FACTOR

A map is drawn to scale to reduce its size. With a scale factor of 1 inch to 100 miles, a map of the United States could be drawn on a paper approximately 35 inches by 20 inches. To be a true representation, the dimensions and relationships of the physical features must remain proportionally constant.

The same principles of scale factoring are used in analog computers. A feature or characteristic of the physical system is used to represent the value of a quantity in the problem. Values such as yards, degrees, functions of an angle, and time may be simulated by values such as voltage, current, mechanical position of an element or one of its parts, and shaft position or rotation.

A scale factor is calibrated into a computing network and remains constant throughout the network. In a circuit where 10 volts represents 10,000 yards, for example, 5 volts represents 5000 yards. Scale factor is a compromise between accuracy and component size. The smaller the scale factor, the more accurate the analog representation and the larger the components. For example, a computer with a 1:2 scale factor is more accurate but has larger components than a similar computer with a 1:4 scale factor.

SUMMARY

From the foregoing discussions we can deduce the following facts about analog computer operations.

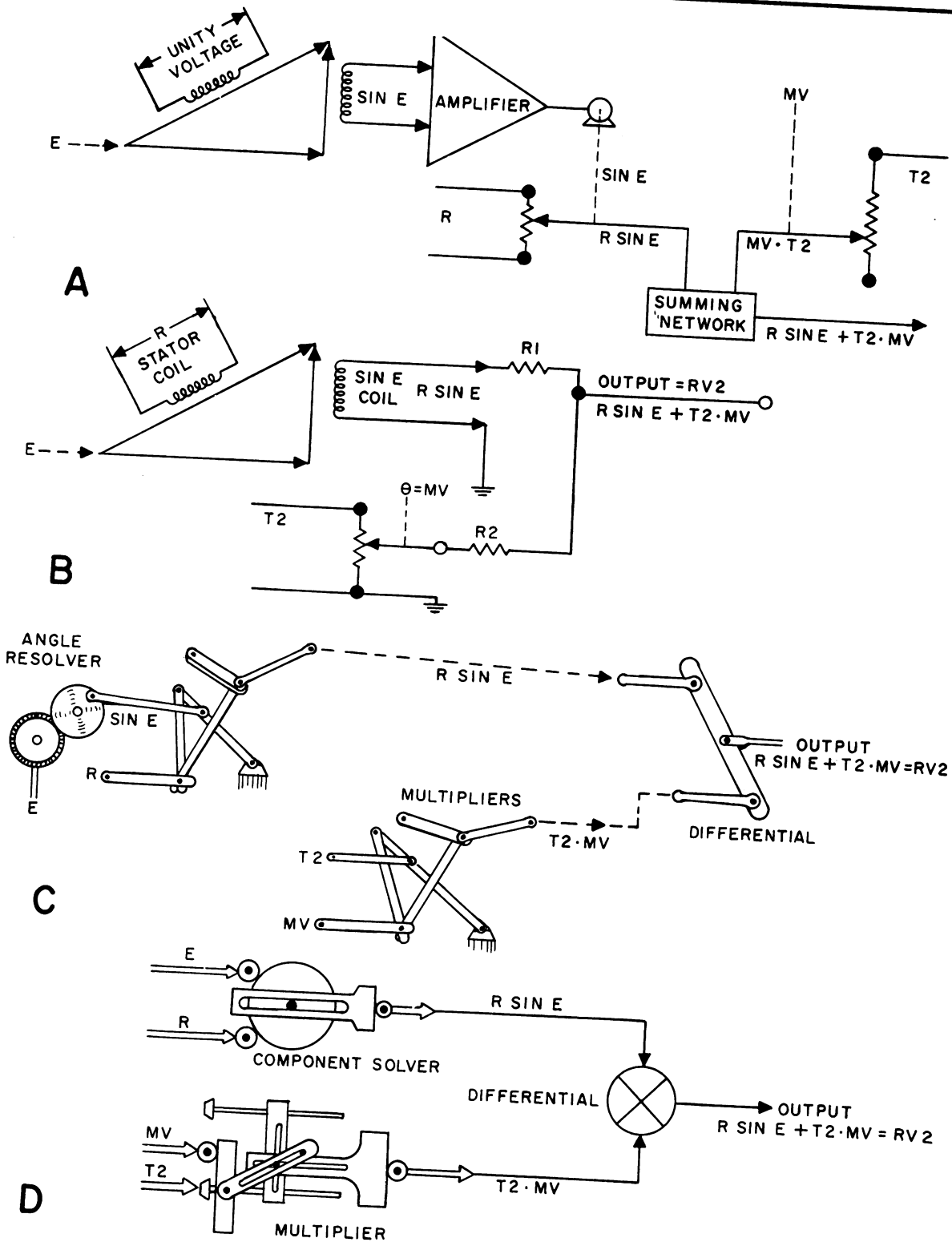


Figure 3-2.—Different types of mechanisms solving the same formula.

1. The problem is simulated in a physical system capable of work.
2. Each computing element solves a discrete problem continuously.
3. Scale factors are used to reduce element size.
4. Different types of computing elements can solve the same problem.
5. The computing elements are interrelated and work simultaneously.

COMPUTER VARIATIONS

Fire control analog computers are highly specialized instruments, designed to satisfy the needs of a particular system. Computer differences result from system considerations, and the various methods used to solve the fire control problem. We will examine some of the major computer variations. Most of the variations center around the methods of establishing target present position and tracking. The computer's predictions vary due to the ballistic differences in weapons. But the methods used to solve the prediction of the LOF have few significant differences. We will not consider the differences in computing elements. The basic elements can be changed and the computing network remains functionally the same.

When you studied the problem for FT 2 you learned that there are three coordinate systems used in fire control, namely, spherical, cylindrical and cartesian. These coordinate systems are used to measure the quantities which define position and velocity with respect to reference lines and planes. The reference lines used are earth's north/south axis, ship's center line, the LOS, and the LOF. The reference planes are the horizontal/vertical planes and the deck/normal planes. A fire control system may employ various combinations of coordinate systems and references.

COORDINATE SYSTEMS

The fire control problem can be solved in any one of the three coordinate systems. Each coordinate system has inherent advantages. The spherical coordinate system's axes coincide with the axes of movement of the directors, gun mounts, and missile launchers. Thus, less coordinate conversion is necessary and fewer computing elements are needed. But computers using spherical coordinates do not use

target height in the computation, although it may be calculated and displayed for external use. The problem is solved using the angle of elevation. In the cylindrical coordinate system, the linear value of target height is used in the computation. Coordinate conversion is necessary. This coordinate system is used when target height can be a dominating factor in the problem. Hence the cylindrical coordinate system is used in many missile computers. The cartesian coordinate system also uses linear target height and is used in some missile computers. This coordinate system is used in shore bombardment computers almost exclusively. These computers solve a target present position problem using an overlay or chart graduated in cartesian coordinates. Target designation systems and weapons director equipment (WDE) use the cartesian coordinate system. In some installations the computer performs coordinate conversion between the fire control system and the weapons direction equipment (WDE).

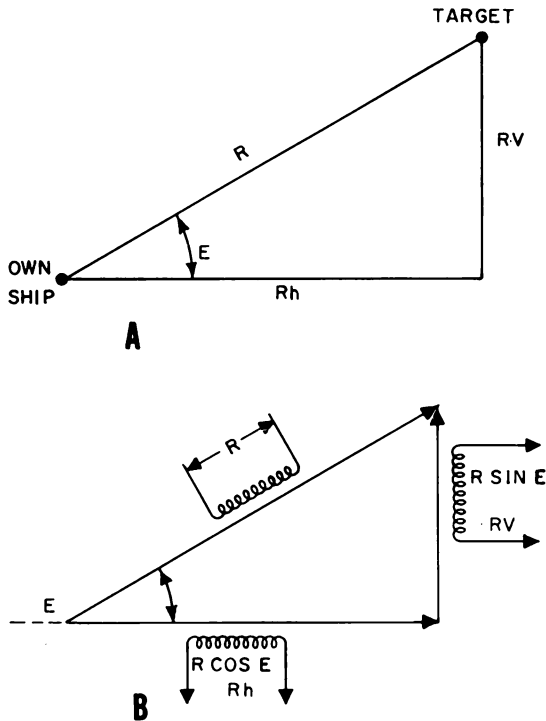
Coordinate Conversion

Computer input data must either be in or converted to the coordinate system used to solve the problem, (referred to here as the computer's coordinate system). In a previous course, conversion between coordinate systems was graphically illustrated. Here we will cover the mathematical formulas and mechanize the conversion with a resolver. (Other computing elements, such as a component solver, can also perform conversion.)

Directors and radars normally use the spherical coordinate system to describe target position. The quantities in this system are bearing (B) and elevation (E) angles and range (R). To convert to the cylindrical coordinate system which uses bearing angle, targets' height (Rv), and horizontal range (Rh), a right triangle is used. From figure 3-3A it can be seen that

$$\begin{aligned} R_v &= R \sin E \\ R_h &= R \cos E \end{aligned}$$

The angle E positions the resolver's rotor (fig. 3-3B). A voltage representing range is an input to one of the resolver's rotor windings. The resolver outputs from the stator windings are two voltages whose values are proportional to Rv and Rh. The bearing angle is the same in both coordinate systems.



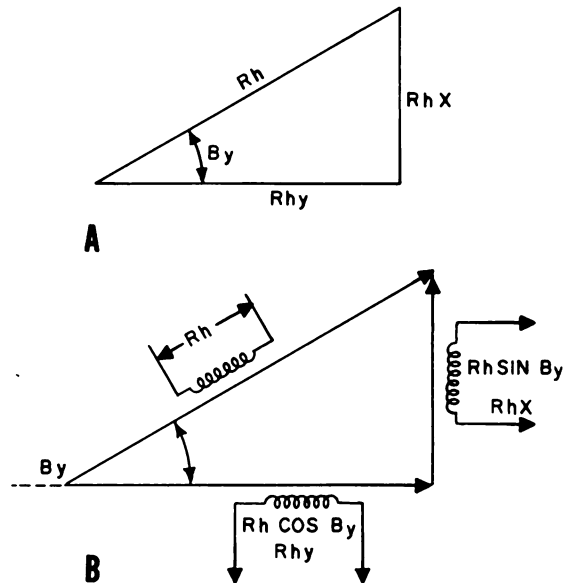
12.110
Figure 3-3.—Converting from spherical to cylindrical coordinate system.

Now let's convert the cylindrical coordinate system to the cartesian coordinate system. In the cartesian system, target position is described by the quantities east/west horizontal range (Rh_x), north/south horizontal range (Rh_y), and target height (R_v). Conversion is accomplished by using a right triangle, as shown in figure 3-4A. It can be seen that:

$$\begin{aligned} Rh_x &= Rh \sin By \\ Rh_y &= Rh \cos By \end{aligned}$$

Angle By positions the resolver's rotor in figure 3-4B. A voltage representative of range is an input to one of the resolver's rotor windings. The outputs from the stator windings are voltages proportional to Rh_x and Rh_y. Target height is identical in both coordinate systems.

When you studied resolvers, you learned that the conversion procedure covered here is called resolution. You also learned that resolvers are capable of performing composition. In composition the two sides of a right triangle are known



12.110
Figure 3-4.—Converting from cylindrical to cartesian (rectangular) coordinate system.

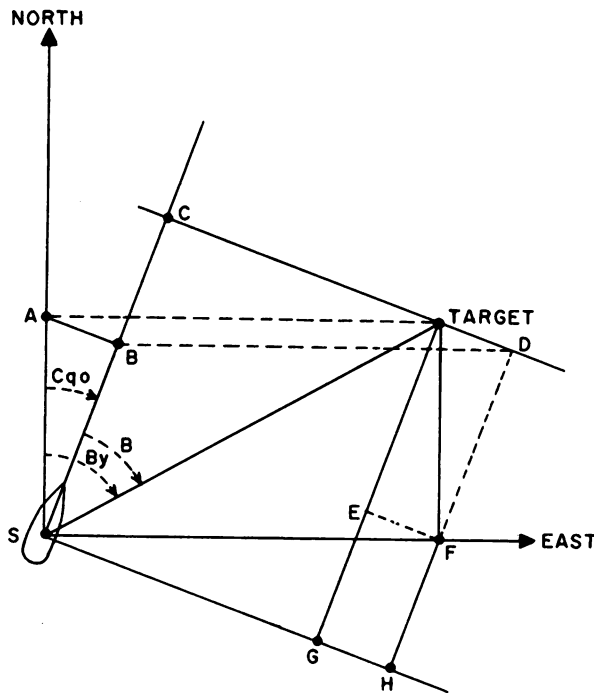
and the vector (angle and the hypotenuse) is the answer. Thus, it is possible to reverse the conversion procedures covered here.

Coordinate Rotation

Computer coordinate systems almost universally use the horizontal/vertical reference planes. These planes give the computer a stable reference frame within which to calculate the problem. As you know, other elements of the system move with respect to the deck/normal planes. Hence data received by the computer or transmitted from the computer to these stations must be corrected. The correction is a matter of rotating the coordinate axes from one set of reference planes to the other. Coordinate axes rotation is also necessary when true quantities are changed to relative quantities. We will use this rotation problem as an example.

The geometry of the problem is shown in the diagram of figure 3-5. The known quantities are:

- C_{qo} (angle ASB) own ship's head
- R_{hy} (line SA) N-S horizontal range
- R_{hx} (line SF) E-W horizontal range
- Quantities Rh_x and Rh_y define target position in rectangular coordinates with respect to the



92.7

Figure 3-5.—Coordinate axes rotation.

earth's N-S axis. We must rotate the coordinate system to define target position with respect to own ship's center line (line SC in the diagram), and an axis perpendicular to the centerline (line SH). Angle Cqo is the amount of rotation necessary.

In the diagram the following lines are drawn:
 line AB at 90° to line SC
 line BD parallel to line AT
 line DF, and continue to H
 line FE at 90° to line GT

First find line SC, ship's center line axis. This is made up of lines SB and BC. If you can find these two, you can simply add them.

Line SB = line SA (known quantity)
 times cos Cqo (known quantity).

Since $\angle ASF$ and $\angle CSG$ are both 90°,
 therefore $\angle FSG = Cqo$.

Since line BD is parallel to SF, and
 CD is parallel to SG; therefore
 $\angle BDC \neq \angle FSG$ Cqo

Line CB = line BD (sin Cqo)
 = line SF (sin Cqo)

Line SC = line SB + line BC
 = SA (cos Cqo) + SF (sin Cqo)

NOW find line SG. If we can find the length of SH and GH, we can get the length of SG by subtracting GH from SH.

Line SH = SF (cos $\angle FSH$)
 = SF (cos Cqo)

Since line TF is parallel to line AS, and line
 TG is parallel to line CS, therefore $\angle ETF =$
 $\angle BSA = Cqo$

Line EF = line TF (sin Cqo)
 = line SA (sin Cqo)

Line GH = line EF (opposite sides of a
 rectangle)

Therefore GH = line SA (sin Cqo)

Line SG = SH - GH
 = SF (cos Cqo) - SA (sin Cqo)

RELATIVE MOTION RATES

Generally speaking, target tracking furnishes the fire control problem with continuous target present position and a means of measuring the relative motion between own ship and target. Target tracking is a closed-loop system with the computer furnishing aided tracking signals. The part the computer plays in the tracking procedure varies with the type of systems. As you know, the relative motion rates are determined and checked by the tracking process. These rates are of two types—angular and linear.

Angular Rate Systems

The director moves angularly in bearing and elevation. A measurement proportional to the director's angular velocity is obtained by using a device such as a rate gyro. Hence the angular rates are available as inputs to the computer. This is a definite advantage. Angular rates are used in most new systems. In the computer these rates are modified into the form desired and into the computer's coordinate system.

Another method of obtaining the relative rates is to compute the velocity of the tracking line, using the radar tracking system as a source of information. Tracking errors proportional to target displacement from the center of the radar beam are represented by voltages. The error voltages are measured in the radar's elevation and traverse axes. These voltages are transmitted to the computer where mathematical operations are performed to obtain the correct relative angular rates. The correct rates are transmitted to the director, and control its velocity. The director's angular velocity is

correct when it equals target relative angular velocity, at which time radar's position error voltages are zero. This type of tracking loop is reasonably simple in actuality, but is complex in theory. Since you deal with the actual system, only that theory necessary to understand its operation is required.

The heart of this method of obtaining the angular rates is the mathematical operations we passed over rapidly. Both rates are obtained by identical operations. To start with, we have an error voltage proportional to a position error which represents a displacement between beam axis and target position. Displacement is a result of motion which implies velocity, for velocity is a derivative of displacement. In other words, for a specific time interval, the amount the director moves is a function of its velocity. This relationship allows us to calculate the director's velocity. The mathematical process of obtaining rate of change is known as differentiation. In this case we are discussing velocity, the rate of displacement. From your study of FC special circuits you know that an RC circuit will differentiate. The output of this type of circuit is the time rate of change of its input.

In figure 3-6 the input voltage to the differentiator is proportional to the director's displacement error, which is a result of an error

in director motion. The output of the circuit is proportional to the acceleration required by the director. The output voltage is amplified, and drives a servomotor which positions the wiper arm of the potentiometer. The wiper arm picks off a percentage of the reference voltage supplied the potentiometer. The voltage picked off is the angular rate sent to the director. The servomotor's shaft position represents the computed angular rate used in the computer. When the director's velocity is correct, the position error is zero and the potentiometer wiper arm is stationary. A constant velocity signal is now furnished to the director. Thus the computer, in conjunction with the director, performs integration. In integration we know the rate at which a quantity is changing, (output of the differentiating circuit), and we desire to find the value of the quantity, (director velocity). The tracking loop was simplified for clarity of explanation. Many added features to provide accuracy and smoothness are used in the equipment.

Angular rates, although convenient for aided tracking, are not as practical for predictions. To obtain smooth predictions, the angular rates are converted to linear rates. Since the computer's coordinate system is stabilized, the rates are rotated to coincide with the computer's axes.

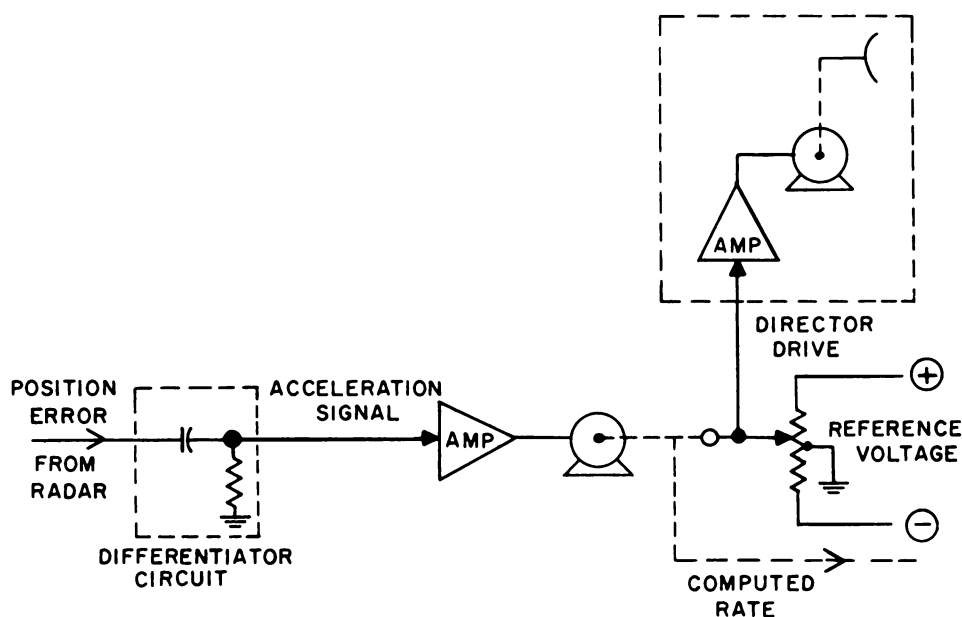


Figure 3-6.—Example of a simplified angular rate computing circuit.

Linear Rate Systems

In linear rate systems the rates are calculated in the computer from three groups of inputs:

1. Ship motion inputs of own ship's course and speed.
2. Target motion inputs of target course and speed; in an AA problem, target speed is resolved into two components—horizontal speed and rate of climb (vertical speed).
3. Target position inputs of target elevation, bearing, and range.

Three rates are computed relative to the LOS: in the LOS (range), across it in the horizontal plane (bearing), and perpendicular to it in the vertical plane (elevation). These rates are based on the position of the LOS at the instant of their computation. The velocity of the LOS is not used directly to determine the rates. This is a disadvantage of the system. However, when aided tracking is used by the director, the velocity of the LOS furnishes a check on rate accuracy. (The linear rates are converted to angular rates for aided tracking.) The calculated linear rates correspond to the computer's coordinate system.

Rate Conversion

Here we will discuss the relationship and the methods of conversion between angular and linear relative rates. Target motion is assumed to be in a straight line at a constant speed. This is linear motion. The director measures this motion from a fixed point by training and elevating the LOS angularly. Target motion is tangent to a tracking circle whose radius is range. The relationship between the target's linear motion and the director's angular motion and the director's angular motion is established by a law of physics which says, "The speed of a point on a body rotating about a fixed axis is the product of the distance of the point from the axis and the angular speed of the body." The relationship between angular and linear rates is established by the formula: $R \cdot D = RD$ where R is range, D is angular rate, and RD is linear rate. And it follows that to find the angular rate, the formula is: $\frac{RD}{R} = D$. Now assume that after the angular rate has been determined by measuring range and director velocity, the target accelerates or

changes course. The motion caused by this acceleration is considered tangent to the tracking circle, and we have a law for this, "The tangential acceleration of a point on a body rotating about a fixed axis is the angular acceleration about the fixed axis multiplied by the distance of the point from the axis." Thus, range times director acceleration equals tangential acceleration. But the effect of target acceleration is normally measured as a linear displacement of the target from the LOS. Thus, to calculate the correct director velocity, we must convert this to angular measure. This is normally done using radian measure. Let's look at the relationship between radian measure and the more familiar degrees and minutes measure. As you know, there are 2π radians or 360 degrees in a circle. Therefore,

$$2\pi R = 360 \text{ degrees and}$$

$$\pi R = 180 \text{ degrees. Consequently}$$

$$1 \text{ degree} = \frac{\pi}{180} = .0174533 \text{ radian.}$$

It happens that there is a close relationship between the radian measure and the tangent function of small angles.

$$1^\circ = 1 \frac{\pi}{180} = .0175 \text{ radian; } \tan 1^\circ = .0175$$

$$2^\circ = 2 \frac{\pi}{180} = .0349 \text{ radian; } \tan 2^\circ = .0349$$

$$3^\circ = 3 \frac{\pi}{180} = .0524 \text{ radian; } \tan 3^\circ = .0524$$

In normal tracking, the target acceleration displacement is extremely small compared to range. Hence, the angle is small and its tangent, target's displacement, is assumed to be equal to the angle expressed in radian measure. Normally the mil, equal to $\frac{1}{1000}$ radian, is used.

Range is a linear quantity throughout the fire control problem. Hence range rate is computed as a linear rate quantity and remains linear.

Tracking Smoothness

The tracking system must respond rapidly, accurately, and smoothly to continuously changing target conditions. As target conditions vary, the requirements placed on the tracking system's response to a target maneuver must also vary. For example, if the target is at close range, i.e., less than 10,000 yards, it presents

conditions that are more severe than at greater ranges. Short ranges require that the tracking system respond more quickly to target maneuvers. The computer furnishes aided tracking and is a convenient place to adjust the tracking system for varying target conditions. As range decreases, the sensitivity of the tracking system is increased. Along with range, tracking sensitivity varies directly with the size of the tracking error.

Here are a few examples of some of the methods used to vary the tracking loop's sensitivity. In systems using rate gyros, the gyro damping is varied. An increase in the damping reduces the gyro's reaction (precession) to small changes in the force applied. The computer's job is to calculate the proper amount of damping for changing target conditions. In systems where the angular rates are calculated, the gain of the rate servoamplifier is varied. The net result of this method is identical to the gyro damping method.

In linear rate systems, tracking loop sensitivity is controlled after the rate has been established. The time required to eliminate an error in the established rate is varied. This is called "rate controlling." Note the difference between the angular rate and the linear rate system of obtaining tracking smoothness. Rate controlling varies the sensitivity of a correction to an established rate, while in the angular rate system the sensitivity of establishing the rate is varied.

COMPUTER SECTIONS

The fire control problem has clearcut divisions which can be readily used to subdivide a computer into functional sections. In essence the problem considers the establishment and velocity of the LOS and the LOF. The fact that we have two reference lines, a tracking line and a weapons line, results in a major division in the problem and in the computer. The ultimate answer is the LOF. This is established by an offset from the LOS. The offset, called the lead angle, is based partially on the movement of the LOS during the weapon's time of flight. Thus the computer has sections which calculate the position and the relative rates of movement of the LOS. Other sections of the computer deal with the corrections necessary to offset the LOF from the LOS, and to correlate their movements. In this discussion of functional

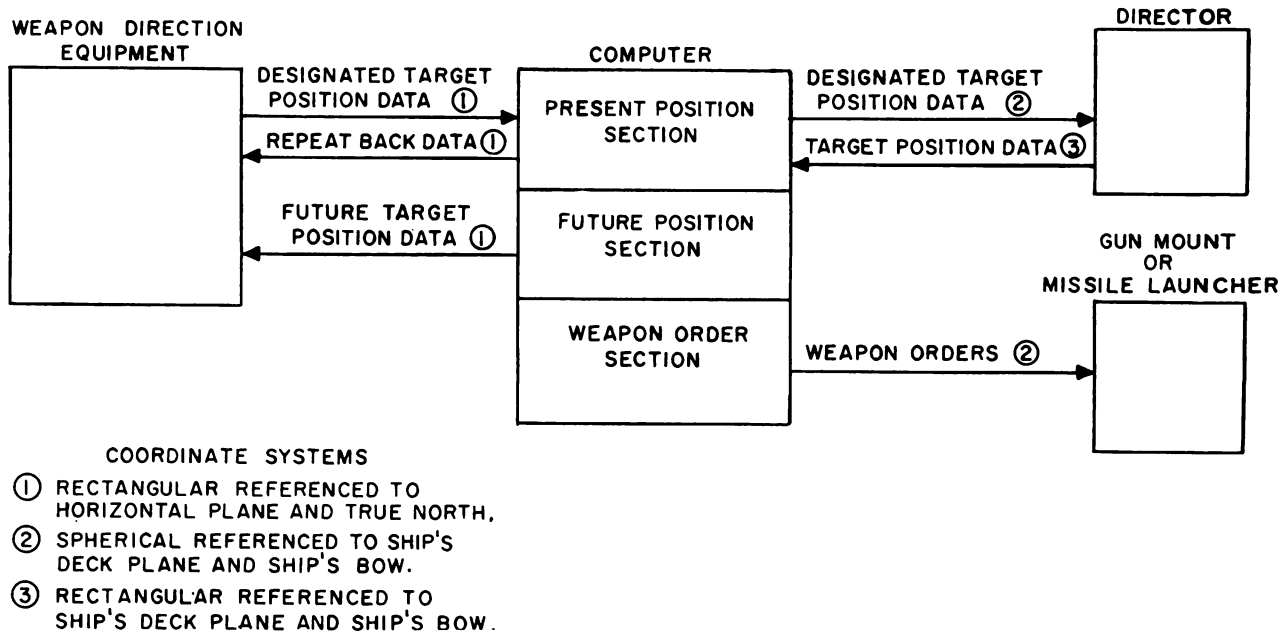
sections we will use a dual ballistic computer with both gun and missile capability. We will not go into the mechanization of the computer but will cover the process or operations used to solve the problem. Fire control computers have the same basic information available and have the same problem to solve. Hence similar functional sections of computers have much in common. Figure 3-7 is a simplified flow diagram showing the general flow of information to and from the computer, and the coordinate systems used.

The mechanisms in a functional section may not be physically located together. This fact will not concern us in this discussion, as it is simply a design feature. As pointed out previously, one of the major differences between computers is in the type of relative rates used. This computer uses angular rates. A computer that calculates linear rates from present target position information was covered in the FT 2 course.

PRESENT POSITION AND RATE SECTION

Logically the first step the computer performs in the solution of the problem is to locate the LOS within itself in the desired coordinate system. The computer receives target present position data from the director (fig. 3-8) in rectangular coordinates referenced to the deck plane. The director measures target position in spherical coordinates, but converts this data to rectangular coordinates prior to transmission. This is done by converting the spherical coordinates to cylindrical coordinates and then the cylindrical coordinates to rectangular coordinates. The procedures and formulas for these conversions were shown previously under computer variations. The conversion to rectangular coordinates is done to facilitate coordinate axes rotation performed in the computer. The computer solves the problem using cylindrical coordinates referenced to the horizontal plane. Hence the target coordinates received from the director must be rotated from the deck plane to the horizontal plane, and converted to the cylindrical coordinate system.

The "deck tilt corrector" rotates the coordinate axes from the deck plane to the horizontal plane, and converts the rectangular coordinates to spherical coordinates. The



92.9

Figure 3-7. —Simplified data flow to and from the computer.

corrector continuously generates values of target elevation angle E , and relative target bearing B , measures with respect to the horizontal, in response to varying inputs. The inputs are target present position received from the director, and ship's roll Z_0 , and pitch E_{i0} , angle. The roll and pitch angles measure the deviation of the deck plane from the horizontal plane. Hence, the amount the axis system must be rotated is proportional to these angles. A separate vector resolver is required for each rotation of the axis system.

The "height and horizontal range" computer shown in the figure converts the spherical coordinates to cylindrical coordinates. The inputs are the spherical coordinates E and R . The outputs are the cylindrical coordinates R_h , horizontal range, and R_v , target height. Relative target bearing is common to both coordinate systems.

The "ship course receiver group" rotates the relative bearing to true bearing axes and converts target position to rectangular coordinates. The true rectangular coordinates measured in the horizontal plane (stabilized) are transmitted to the WDE as repeat back information.

The "range receiver group" converts range received from the radar to shaft position and

voltage representations. Each representation has a scale factor incorporated.

Angular Rates

The radar's angular tracking system generates error voltages proportional to target's displacement from the center of the radar beam. These voltages are transmitted to the computer as an elevation tracking error signal e (elevation) and a traverse tracking error signal e (traverse), (fig. 3-8). The computer uses these voltages to calculate angular elevation rate, DE , and angular bearing rate, DB_{sd} . These rates are calculated as explained in the section under computer variations. But to obtain maximum smoothness of the tracking system while still maintaining minimum response time, modifications are included in the rate computation.

The tracking error signals are proportional to target displacement measured in mils. To obtain an acceleration signal, the displacement error must be converted to a velocity error. This requires a time factor in the problem, since velocity is equal to displacement divided by time. The entrance of the time factor provides the computer with means for modifying the tracking loop response to varying tracking conditions.

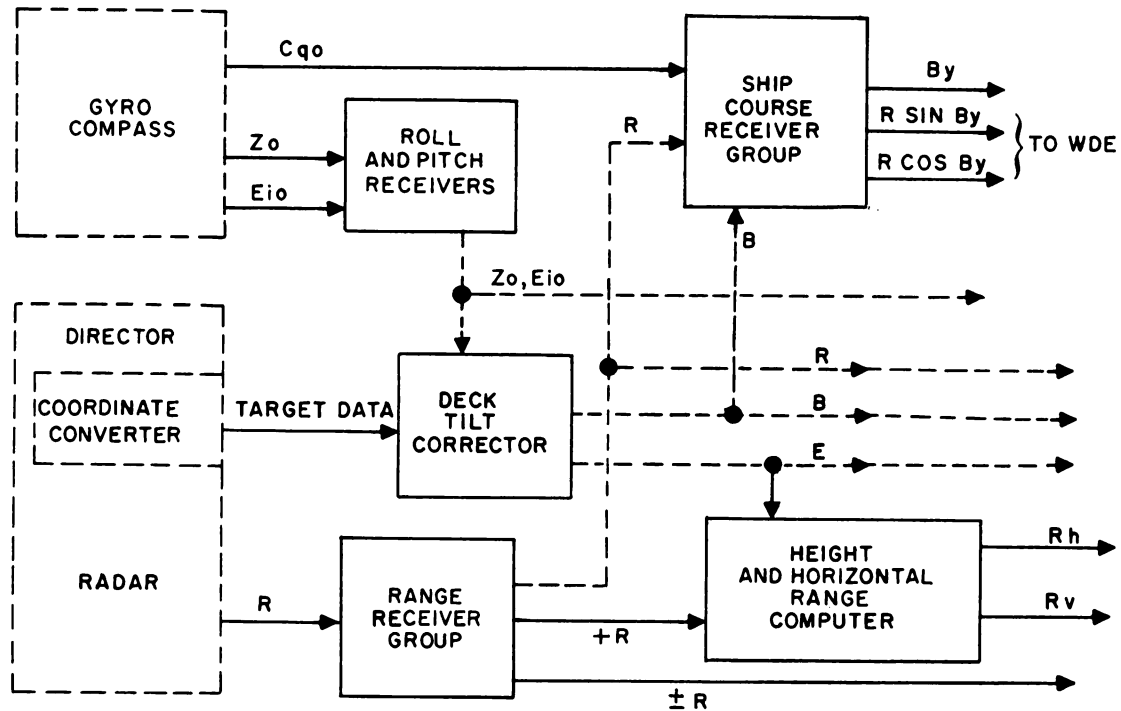


Figure 3-8. —Present position section.

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As you know, response must be more rapid at short ranges and for large tracking errors. The time factor consists of a constant rate signal voltage expressed in mils per second, which is multiplied by a voltage proportional to inverse range variable, $\frac{1}{R}$, and a voltage which is a function of the sum of both tracking error signals. The resulting voltage is proportional to a predetermined rate modified indirectly by range and directly by a function of the tracking errors. This voltage is used to drive a servosystem whose output positions potentiometers in the input circuits of the angular rate servoamplifiers. These input circuits contain differentiating circuits whose R component is varied by the potentiometers. The input to the differentiator is the tracking error; the output is the time rate of change of this error modified by tracking conditions. This acceleration signal is applied to the angular rate servoamplifier.

The rate computation up to this point is adequate for tracking targets at long range, with calm seas. In order to obtain error-free tracking under conditions of close target range and rough seas, however, two more compensating factors are necessary. These compensations are inputs

to the rate servoamplifiers, and are called the range rate and cross traverse compensations.

RANGE RATE COMPENSATION is necessary to prevent the radar from lagging a straight-line constant-velocity target at short ranges. This lag is encountered because director motion is angular, while target motion is linear and is tangent to the tracking arc. Linear target motion is not affected by range, whereas director velocity, being an angular measurement of the linear motion, is affected by range. The change in angular velocity due to a change in range is inversely proportional to range and directly proportional to the magnitude of range rate and the angular rate. Instantaneously, the angular rate has a constant velocity since target motion is constant, but range is changing. A signal is applied to the rate amplifier which is directly proportional to the product of the rate factors divided by range. This compensating signal continuously introduces a correction to the angular rate for range changes.

CROSS-ROLL COMPENSATION has a dual role in rate correction. The director mounted to the deck moves with the deck when the ship rolls and pitches, whereas the radar antenna is

space-stabilized by the traverse, elevation, and cross-roll gyros. Ship's roll and pitch causes a rotation of the director about the LOS. This rotation imparts an erroneous acceleration component to the traverse and elevation gyros, tending to drive the radar off target. The output of the cross-roll gyro is a function of the velocity of rotation; hence it is used in the correction. Cross-roll compensation also corrects for an interchange of function between the traverse and elevation gyros which takes place when the LOS is elevated and the deck is tilted. The amount of interchange is determined by the amount of deck rotation about the LOS. This is measured by the cross-roll gyro. The effect of the interchange is related to target motion in the traverse and elevation planes as measured by their respective gyros. The cross-roll compensation signals correct the angular rates for the erroneous acceleration signals due to LOS rotation, and for target motion in an elevated plane when the deck is tilted.

The outputs of the angular rate servoamplifiers drive servomotors. The motors' shaft positions represent DE and DBsd. The servomotors position potentiometers which furnish the director drives with computed velocity signals. The director drives are velocity servosystems in track mode. The angular velocity of the director is measured by rate gyros. Voltages from the gyros, proportional to director velocity, are amplified and compared with the computed rates. When they are equal, the director is moving at the correct rate. Director drives are covered in a later chapter.

Stabilized Linear Rates

The stabilized linear rates used in prediction are: horizontal range rate DM_{rh} , linear bearing rate DM_b , and rate of climb DM_v (fig. 3-9). These rates are derived from the angular line of sight rates DE' and DB_{sd} , and range rate DM_r . This is accomplished by first multiplying both DE' and DB_{sd} by range to obtain linear rates RDE' and RDB_{sd} . However, the angular rates, and consequently the resulting linear rates, are referenced to the deck/normal planes while the stabilized rates must be referenced to the horizontal/vertical planes. By rotating the coordinate axes of RDE' and RDB_{sd} through the cross-traverse angle, Z_s , the linear rates are referenced to the horizontal plane. The angle, Z_s , is the amount the deck plane deviates from the horizontal plane. To obtain the rates DM_v and DM_{rh} , it is necessary to resolve the linear

elevation rate and range rate about the elevation angle. Both the rotation of the axes and the resolution of the rates are done using standard mathematical formulas.

WEAPONS ORDERS

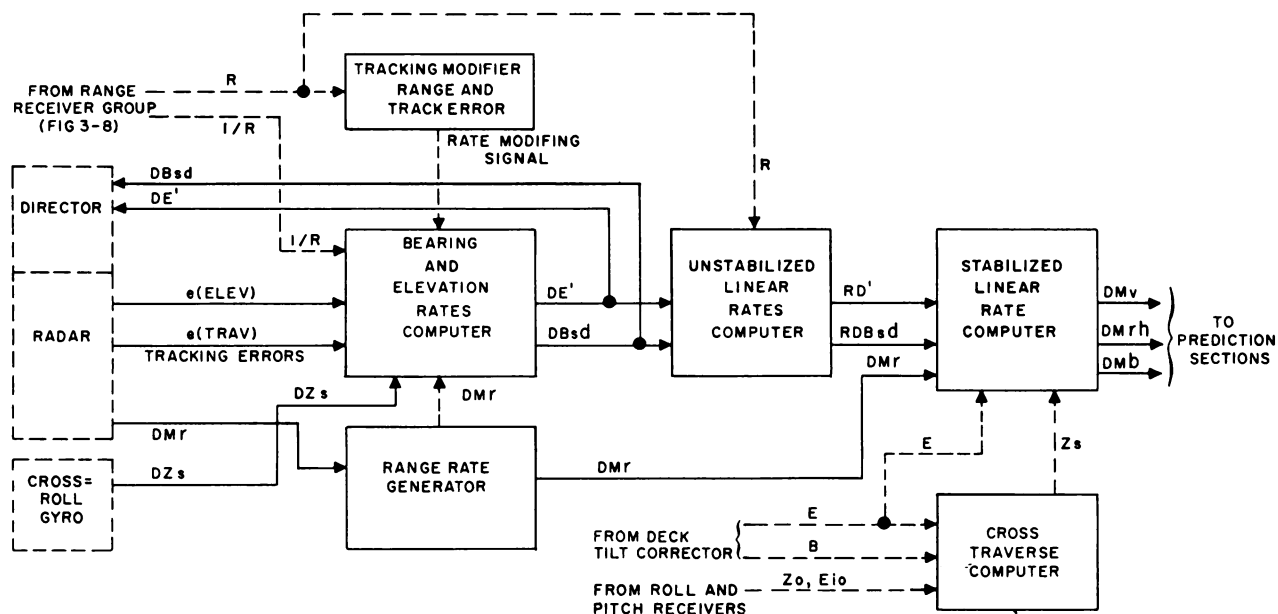
The computer was described as having both gun and missile capability. But nothing more was said about this dual capability because the problem dealing with the LOS is common to both weapons. It is only where the weapon's ballistics enters the problem that there is a division.

The weapon orders are solved in a straightforward manner. First, a future target position is predicted. This is done by multiplying the linear rates by time. The time factor varies with the ballistics of the weapon and is equal to time of flight or a preselected portion of the time of flight. The next step is to compute a point of aim based on future target position. The point of aim and future target position are not coincident due to the weapon's ballistics (such as superelevation and drift). The weapon orders are based on the point of aim. Corrections to the weapon orders, trunnion tilt for example, are made and the corrected orders are transmitted to the weapon.

This computer has three major weapon order sections: launcher, missile, and gun. You will find subsections in the major sections with similar functions, but the value of the quantities in the sections will vary.

Launcher Order Section

We will briefly discuss how the different types of missile guidance affect the launcher order problem before proceeding to the computer. The prediction of the point of aim for missiles with beam-riding guidance is based on the time elapsed between missile firing and missile capture in the beam. Hence prediction is based on a fixed time interval. The launcher order problem is to predict beam position at the time of capture. This position is determined by the fixed time and the relative rates. However, if the missile is not a beam rider, but strictly a homing type, the time elapsed in the launcher order problem differs. Here the time considered is the interval required for the missile to travel to an imaginary point of aim located approximately at target future position. Hence, time is a varying quantity in this launcher order problem. The



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Figure 3-9.—Simplified angular rate section.

major difference between the two problems is the time factor. We will use the latter type guidance since it presents a more severe problem to the computer.

The stabilized linear rates are multiplied by the missile's time of flight, T_2 , to obtain target motion during T_2 . The addition of these quantities to target present position gives target's future position. But future horizontal range and deflection angle contain a parallax correction. The parallax problem is solved in a conventional manner and the corrections are added to horizontal range and bearing components of target motion. Future horizontal range also contains a correction for complementary error due to deflection prediction. Future horizontal range and the deflection angle are computed using a right triangle and the mathematical process of composition. One side of the triangle is proportional to the horizontal range component of target motion, and the other side to the bearing component of target motion. The hypotenuse of the triangle is equal to future horizontal range, and the working angle is equal to deflection angle.

BALLISTICS AND LAUNCHER ELEVATION.—We solved for future target position using time of flight, T_2 . Now we must find T_2 .

This may appear backwards, but the computer has to start somewhere. An arbitrary value of T_2 is used to start with. The future target position is computed using this value of T_2 . The future target position is then used to compute a corrected value of T_2 . This process is continued until a correct value of T_2 , and thus correct values of future target position, are obtained. What it amounts to is a regenerative problem. T_2 is computed for actual missile flight time. Consequently, a correction for superelevation is added to future target height in the computation.

The launcher elevation order angle is a function of future horizontal range, future target height, and superelevation. Launcher train order is the sum of deflection angle and present bearing angle. Compared to the makeup of the gun orders, which was covered in a previous course, the launcher order problem is relatively simple.

Launcher orders are computed in the horizontal plane. The launcher moves with respect to the deck plane. Hence, coordinate rotation is necessary. This rotation is accomplished in the "trunnion tilt corrector." This corrector operates on the LOF quantities much as the deck-tilt corrector did on the LOS quantities, except that the reference planes are reversed. The outputs of the corrector are launcher orders Edg' and Bdg' referenced to the deck plane.

Missile Order Section

While the missile is on the launcher it continuously receives missile orders from the computer. These orders are stored in the missile until they are used to control its flight path to the target. Missile orders and their number vary between missile guidance systems. We will cover two of the basic orders: Seeker Orders and Launcher Cross-Roll Order for homing type guidance. Keep in mind that there are other orders.

SEEKER ORDERS.—The missile contains a highly directional radar antenna called the seeker. When this antenna is pointed at the target, it will receive target echoes. The source of the radar energy is the ship's fire control radar. When the seeker acquires the target, the missile homes on the target. The seeker system is activated after missile booster phase. Since the missile is in the LOF, it must "look over its shoulder" so to speak to locate the target. The seeker antenna moves about two axes called "A" and "B". The "A" and "B" order angles are calculated in the computer by predicting the relative positions of the target, the missile, and the missile's attitude at seeker activation time, which has a fixed value. A representation of the seeker orders equal to a function of their sum is transmitted to the WDE for tactical evaluation.

LAUNCHER CROSS ROLL.—The missile's attitude during booster phase is determined by the launcher's attitude with respect to the deck plane. The computer sends launcher cross roll, Zg, to the missile so that it may orient itself to the local vertical. Cross-roll angle is the deviation of the deck plane from the horizontal plane at the launcher. The fire control system uses the local vertical to establish its stabilized reference frame. Thus the computer can base seeker orders on its vertical plane.

Gun Order Section

The gun order section of this computer is similar in function to the AA computer covered in the FT 2 course. It will not be covered in detail here. Generally speaking, the orders TRAIN, ELEVATION, and FUZE are computed in three steps:

1. The future position of the target is predicted, using the projectile's time of flight.

2. Ballistic data are computed. These consist of the initial velocity, air density, wind corrections, and the computation of the time of flight. The ballistic data are used to compute the point of aim.

3. The last step is to correct the orders for trunnion tilt and parallax (vertical and horizontal).

MODES OF OPERATION

The description of the modes of operation discussed here is of an AA computer with missile and gun capability. The computer operates in three basic modes: AIR-READY, DESIGNATION, and TRACK. The names of the basic modes may vary between computers, but the computer's functions in like modes are similar. Up to now we have concentrated on the computer's solution to the fire control problem. Now you will find that the computer as a part of a system has other functions to perform. These functions, although essential to successful system operation, are not necessarily pertinent to the basic problem.

AIR-READY MODE

In the air-ready mode, the computer is energized and is in a standby condition. The necessary switches to interconnect the computer with the fire control system are ON. Manual inputs are set in the computer. The computer furnishes signals to automatically put other units of the system in their air-ready position. For example, the director/radar would receive from the computer range, bearing, and elevation signals to place it in a selected position. The computer has control of the brakes in the director's drives. Information, such as director position and the status of the fire control system, is transmitted from the computer to the WDE. The computer is taken out of the air-ready mode and put in another mode of operation by an external signal.

DESIGNATION MODE

The sequence of operation is normally from air-ready to designation mode. In conventional gun systems the computer plays little or no part in the designation mode. Target designation is

transmitted from the TDS or WDE to the director/radar. But missile computers have a major part to play in the designation mode. The computer's job in this mode is determined by the reliability of the designated elevation, the range to the target, and the designation system's coordinate system.

The designation mode is divided into submodes according to the source of designation. The submodes vary between installations. But a simplified overview of the computer's job in the designation mode is:

1. Transmit signal to release director brakes.
2. Convert the designation coordinate system to the director's coordinate system if necessary.
3. Transmit signals to drive the director to designated position.
4. Transmit signal to position radar range to designated range.
5. Remove acquisition lockout signal when director is approximately at the designated position.
6. Compute a search pattern and initiate search program.
7. Transmit signals to the radar to shift pulse repetition rate.
8. Transmit repeat-back data of director's position.

The computer's first four jobs are self-explanatory, but the remaining jobs probably require explanation.

The acquisition lockout signal blocks the radar from locking on a target. This signal eliminates the possibility of locking on the wrong target while the director is slewing to the designated target. The computer compares designated position with director position. When these two are approximately in agreement, the acquisition lockout signal is discontinued.

Designated information can be received from various sources. When the designation is received from an accurate source, such as another fire control system, the computer does not originate a search program. But when the designation information is not accurate, the computer generates an acquisition search in bearing and elevation about the designated position. The search patterns are designed to obtain the best possibility of target acquisition in the shortest time. These patterns are determined by the reliability of the designated elevation and target range. Bearing and range designation is normally within the required accuracy. The com-

puter generates signals which modify the designated bearing and elevation sent to the director. The modifying signals vary sinusoidally. The elevation modifying signal's frequency is higher than bearing's frequency. Hence, the director makes faster and more elevation sweeps about the designated position. The magnitude and frequency of a search cycle about the designated position are increased by the elevation unreliable signal.

If the fire control system has a pulse doppler radar, the pulse repetition rate (PRR) is varied by a signal from the computer during search. This is done to ensure against missing a target flying at blind velocity and to compensate for the range ambiguity of this type of radar. To detect a target, the sampling rate of the doppler frequency cannot be more than one-half the PRR. When the sampling rate is more than one-half the PRR the target is said to be moving at a blind velocity. To avoid this the radar is shifted to a higher PRR. Range ambiguity is caused by the fact that at a high PRR more than one transmitted pulse is in the air at a time. This makes it possible to gate a target in the wrong range interval. Shifting the PRR will eliminate this possibility. The shift is synchronized with the search pattern so that one PRR is used during one complete search cycle, and on the next cycle another PRR is used.

The director's position is transmitted to the WDE as repeat-back information. The designated position can be compared with the director's position.

The search program is interrupted by a target echo signal from the radar. The echo signal locks the search program at the offset from the designated position at which the target was detected. The director will continue to be driven by the designation values plus the constant offset of the search program. If the target echo is lost, the search program will resume. If an "on target" signal (radar locked on) is received, the designation mode is terminated and track mode initiated.

The fire control system can be reassigned to a new target by the WDE. A "break track" signal is sent to the computer. This signal discontinues the computer's operation, either track or search, and reapplies the acquisition lockout signal to the radar. The computer receives the new designations and transmits signals to slew the director to this position.

TRACK MODE

The track mode can be divided into submodes of AA, surface, and shore. This of course is determined by the fire control system and weapons capability. AA is the normal track submode. The computer solves the air problem, as we explained earlier. There is an exception to this solution for targets at low elevation. At low elevations sea return (noise) can cause the radar to lose the target. To prevent this, the computer substitutes a fixed value of elevation for target elevation and drives the director to this fixed value. This is not a large offset, and the radar still receives target echoes. Thus the radar does not track in elevation, but continues to detect elevation errors. The computer's control of elevation is similar to that used in conventional systems with a surface mode of operation.

When a missile has surface-to-surface capability, its computer has a surface submode. Computer operation in this submode is similar to that for a low angle air target. The solution is based on a fixed elevation.

In the shore submode, computer operation is similar to that for the surface submode, except for target data inputs. One of the major difficulties in shore bombardment is determining target location. The position of shore targets cannot always be measured by the fire control director. Consequently, target information is measured indirectly. A second fire control director and special shore bombardment computer are used to define target position with respect to own ship. Shore bombardment is covered in chapter 7 of this course.

COMPUTER TESTS

In previous sections nothing was said about the personnel who operate the computer. Modern fire control computers are almost fully automatic in all modes of operation. The computer replaces human judgment by mechanical reaction. Therefore, the computer's solution must be reliable and valid. By reliable, we mean that identical values in the computer always produce an identical solution. Valid refers to the correctness of the solution. Validity can be measured only by comparison with an external criterion.

Each computer has a specially designed test to indicate whether the computer is performing properly. We are not concerned here with the

step-by-step procedures of the various tests; these procedures are covered in the applicable OPs. We are primarily concerned with the use of these test for troubleshooting.

We can divide computer tests into three general classifications: PRELIMINARY, ROUTINE, and UNIT. Preliminary tests are operational checks; they are performed first. Routine tests simulate actual tracking conditions and problems. These tests are for checking the overall operation of the computer. Unit tests are checks of the individual computer elements or sections. In these tests the interrelationship between elements is broken, and the unit under test is checked as an independent component.

PRELIMINARY POWER TEST

The preliminary power test indicates whether the computer is being supplied with the proper voltages. These voltages are used in the computer for the generation of displays, switching signals, and transmission of data. Computations performed in the computer are based on scale factor. These voltages are the basis of the scale factor. Obviously voltage potentials, d-c polarities, and a-c phase relationships are critical in all modes of computer operation.

Supply voltages are checked by specially designed test circuits and installed meters. Normally a check of the computer's control setup, and meter readings of the monitored power supply voltages, is all that's necessary before proceeding to the routine tests. If computer operation is generally erratic or sluggish however, a further check of the power supplies is indicated.

Power supply circuits are extensive. Consequently the first step is to localize the casualty to a particular supply. Study the computer's operation and note the symptoms of any malfunction. This should indicate the sections or elements affected by the casualty. Determine from this information the wiring diagrams to study. Logic will tell you that if a particular supply is common to all the malfunctioning elements, but not used by elements operating normally, it is the cause of the malfunctioning. The next step is to locate the casualty by a point-to-point check of the suspected circuit. Troubleshooting procedures in the OP will tell you the correct reading, tolerances, and type of meter to be used. Remember, test readings can be misleading and erroneous when the effect of the

meter on the circuit being checked is not considered. Be sure of your test equipment, and use the test points indicated in the troubleshooting chart.

ROUTINE TESTS

Routine tests are normally held daily. A record of the test results is kept in a special log issued as a NavWeps form. The theoretic answers determined mathematically and the computer's answers, both past and present, furnish a basis for evaluating the overall operation of the computer. Routine tests can be divided into two general classes—static and dynamic.

Static Tests

In static tests, sometimes referred to as "A" tests, we stop a normal problem at a fixed point. Thus the input test quantities have a constant value, and the problem has fixed answers which do not change with time. As noted previously, some computers receive relative rates from the director. In these computers a static test does not check the determination of the rates. The rates are known inputs to the test. But any computation performed in the computer on these rates is checked. Dual ballistic computers solve separate prediction problems for weapons of different ballistics. These computers have separate answers to the tests for the different ballistics. The test values are inserted manually, and usually require switching from the normal mode to a test mode. Upon completion of the test, be sure that all switches are returned to normal mode.

Dynamic Tests

Dynamic tests are a check of the target tracking loop in the computer. Since there are variations between tracking systems, there are variations between dynamic tests. First we will consider linear rate computers. In this type of computer the rates are calculated in the computer, and time, represented by shaft rotation, is present in the generating section. This means the test values of the relative rates can be established by the computer, and the problem run for a given time interval. This is an ideal test situation. The test answer is the amount of generation of the quantity or quantities under test. When

the tracking loop is completed by the director, special dials in the computer are used to read the amount of generation. The relative rates remain fixed throughout the test. This type of dynamic test is called "B" test. Each of the generated quantities (range, bearing, and elevation) has a separate set of tests. When the computer is regenerative, that is the tracking loop is complete within the computer, a different type of dynamic test is used. In this type, called "C" test, the generated changes feed back into the present position quantities. Consequently, the rates are continuously changing. The test answers are once again the amount of generation, but now the answers are read directly from the present position quantities. All the generated quantities are checked in a single test.

Rate control, as you've learned, is the process of correcting the relative rates in linear rate computers. The rate control test is a check of the time required by the rate control system to reduce a known rate error by a given percent. This type test is run on computers that are not regenerative.

Dynamic tests are run on some angular rate computers by using a special test set. The test set is substituted for the director, and completes the tracking loop. The tester generates a problem which simulates a target flight and introduces sudden variations in target range, bearing, and elevation. The computer performs as it does for an actual problem. The computer's solution is transmitted to the tester, where it is compared with the correct solution. Errors are monitored by indicating lamps, which are preset to light when the error exceeds the allowable value. To obtain a detailed analysis, the indicator lamps are bypassed and the error voltages are transmitted to an error recorder.

UNIT TESTS

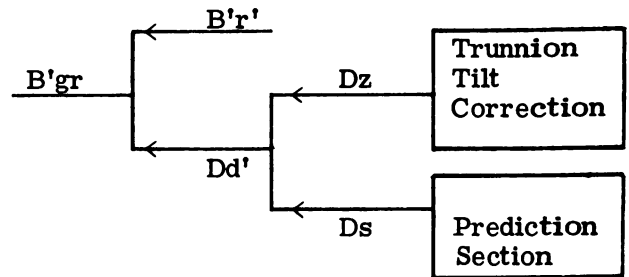
Unit tests are checks of individual computing elements or related groups of elements. Some unit tests are performed periodically, and could come under the heading of routine tests. If a computer section is not checked by routine tests, a set of unit tests is performed for that section. An example is the deck-tilt corrector in some angular rate computers. The "A" test input quantities are in the horizontal plane, and the deck-tilt corrector is bypassed. A unit test is performed at regular intervals to check this section.

ANALYSIS OF TEST ERRORS

The majority of unit tests are used during analysis of routine test errors. The unit tests reveal malfunctioning or adjustment errors of an individual section or element of the computer. Since many variable functions contribute to the solution of a fire control problem, an error introduced anywhere in the computing process could produce an excessive error in the final solution. This makes it impractical to resort to unit tests as soon as an error is detected. Instead, a complete set of static tests are performed. A static test is indicative of only one fixed condition of a problem which in its normal state is dynamic. To obtain all the relevant circumstances surrounding the error, we should observe the problem from as many viewpoints as possible. By running a complete set of tests, the effects of modifying factors on the quantity in error can be noted under varied conditions. The values of the input quantities in the static tests are changed so that the effect of each modifying factor varies between tests. We can think of the test as a series problem in that the modification or generation of a quantity is done in steps. The correctness of each step is dependent on the previous operation to the quantity. However, some modifying factors effect more than one final quantity. Hence the modifying quantities perform separate operations simultaneously on more than one final quantity. The modifying factors are called intermediate quantities. The input and the intermediate quantities make up the final quantity. The deviation of a final quantity is referred to as its "family tree."

Let's take the quantity gun train order, $B'gr$, from the Rangekeeper Mk 8, and use it as an example to show a family tree. At the same time, we analyze an "A" test error. This particular quantity was selected because the problem as solved by the Mk 8 was covered in the FT 2 course. Both the standard symbols and those used in the Mk 8 are given.

Assume that, on examination of the "A" test results, you find that the errors in $B'gr$, (Bdg'), are greater than the allowable values. $B'gr$ is equal to director train $B'r'$ (Bd'), plus the total deflection in the deck plane, Dd' , (Ld'). Furthermore, Dd' is the addition of trunnion tilt correction Dz , (Lz), and sight deflection Ds , (Ls). To illustrate this much of the family tree we have:



To analyze the "A" test errors in $B'gr$, you must consider the intermediate quantities one at a time. The first thing to check is the $B'r'$ input. From your study of the fire control problem you know that $B'r'$ is a basic quantity that affects all other deflection quantities. Consequently, an error in $B'r'$ will result in an error in Ds . The relationship between the two quantities is considered by comparing the test readings. Unit tests are run on the $B'r'$ followup, and on any other element that has $B'r'$ as an input. The procedures for running the unit tests are given in the OP. Next, after assuring yourself that $B'r'$ is not the cause, check the test readings of Ds and Dz . The trouble will necessarily have to be in one of these two. Let's say it is in Dz , and that the Dz followup is working satisfactorily. Then, of course, you have the error localized to the trunnion tilt corrector. To locate the exact source of the error, it is necessary to run the trunnion tilt corrector tests and unit tests on its individual components. These tests will show what adjustment is necessary.

Now if the error has been found to be in Ds , the same procedure is used to trace it down. First analyze the test results; then, referring to the schematic, find out what goes in to make up Ds . Finally, eliminate each unit involved, by unit tests, until the source of error is found.

Test Sets

The preceding discussion dealt with an electrical/mechanical computer. Basically, the same procedure for analyzing a test error in electronic/mechanical computers would be followed. After the source of the error has been localized to a section, unit tests are performed. The unit test gives voltage readings to be taken at various test points. The voltage readings are a check of the individual components and circuits in the section. The computer depends on the proper operation of electronic units such as servo, resolver, and computing amplifiers, modulators, demodulators, and phase shifters.

Test sets are provided to check the operation of these units. The test set provides the unit with the necessary input voltages and the proper operational load. A means for monitoring the input, output, and null voltages, and the point-to-point check voltage, is provided in the test set. If a suspected source of a test error is in a network which includes electronic units, checking with the test set will eliminate these units as the possible error source.

Plug-in module units are removed from the computer and tested. The test set supplies all the necessary power, and only the unit is tested. The computer's circuitry and supplies are not checked. If you are reasonably certain that the error source is from or around the tested electronic unit, the next step would be the computer's circuits. That is, power supplies, signal sources to the unit, and the load of the unit. Where the electronic units are checked in the computer, the test set usually substitutes its signal inputs for the computer's, and the unit's output is either substituted or monitored. The computer's power supplies and circuitry are used to a varying degree in these tests. Consequently, you must study each test procedure to see exactly what is being tested.

TROUBLESHOOTING

The computer test results and operation are well within the allowable values when the computer is installed aboard ship. An excessive test error indicates a deviation from the original condition. Past test results will indicate whether the deviation is the result of a gradual, cumulative change, or of sudden defect or failure.

Computer operation causes wear in mechanical parts. The wear is cumulative, and results in lost motion. Lost motion is particularly critical in low tolerance computer gearing. As lost motion increases, computer reliability decreases. Lost motion causes random computational errors. You can see this effect at its worst if you first set the test values from one direction and record the results, then reset them from the opposite direction and record the results. The difference in the results is the effect of lost motion. The accumulated lost motion in gear train can be felt by holding the gear at one end stationary and turning the gear at the opposite end of the line slowly back and forth. Lost motion between any two points on a shaft line can be checked in the same manner.

The mechanical lines are subject to sticking or jamming caused by dirty or damaged gears or bearings, bent shaft, or improper gear mesh. Sticking means that one or more parts move sluggishly throughout their normal travel, or resist moving past certain points. A sticking part may jam eventually if the cause is not eliminated. Jamming means that one or more parts which should move cannot be moved by normal force, usually hand pressure. The amount of force necessary to move a line is determined by the load on the line, and you must judge each line accordingly. Never force a jammed or sticking line to turn. Use the lost motion check to locate the source of trouble in a particular shaft assembly or gear mesh. In a jammed or sticking line, the farther a gear mesh is from the point of the trouble, the more accumulated lost motion can be felt in it.

Slipping, or failure of all the assemblies in a shaft line to turn together, may be caused by loose hangers, stripped gear teeth, loose clamps, or missing or sheared taper pins. To locate a particular assembly which is slipping, follow a procedure similar to that used to check lost motion.

Electrical Troubleshooting

The electrical and electronic circuits in computers are usually complex and extensive. Circuit voltages and currents are critical; therefore, the circuit components have low tolerances. But normal electrical troubleshooting procedures for shorts, opens, and grounds can be followed. Troubleshooting charts or diagrams give a systematic procedure to follow, along with the correct readings. The troubleshooting chart usually includes possible causes of an improper reading at the check points. Most electronic assemblies are checked as a unit by a special test set. If an assembly proves faulty, make a point-to-point check.

High voltages, capable of causing death, are used in computers. Dangerous potentials may exist in capacitors after power shutdown.

Computer Adjustments

Adjustments are provided to establish the proper relationship between components. This relationship is checked by computer tests. Therefore, you will be adjusting in the blind without tests. When running a test, take care to

make precise input settings. Before analyzing the results of routine or unit tests recheck the computer setup, recalculate the error, and rerun the test. Before you rerun the test, recheck the computer control switches and power supply indicators. These preliminary steps will eliminate unnecessary troubleshooting, and in the long run save you time and needless worry.

After the source of trouble has been localized to an individual component, the experienced technician will stop and study the computation of the quantity in error and reexamine the test run. Before making an adjustment he will study the computing network to see exactly what effect the adjustment will have on the network, keeping in mind that the adjustment may affect other components and quantities. After the technician is satisfied that he knows exactly how to make the adjustment, and what the effect of the adjustment will be, he will be ready to start adjusting.

Adjustment procedures are outlined in detail in the computer's OP. Broadly speaking, the adjustment procedure considers the component's inputs, function, and outputs. The inputs are set at a test value. The component modifies the input values by its designed function. Thus the outputs have a definite relationship to the inputs. The adjustment is made so that the output values have the correct relationship to the input values. After the adjustment is made, rerun the component's unit tests.

An adjustment in a computing network may offset the correct relationship between components. For example, you may have adjusted a component with an output connected to a limit stop which controls the operational values of the output quantity. But this quantity is related to the component's input which you have adjusted. Therefore, the limit stop must be checked and possibly adjusted. This holds true of all the components which could possibly be affected by the adjustment.

CHAPTER 4

WEAPONS CONTROL SYSTEMS

INTRODUCTION

In the FT3 course, NavPers 10173-A, we gave you a brief outline of a shipboard weapons system and discussed the basic functions of its units. We did this to give you a broad overview of a typical system, and to show the details of the fire control problem and system units in their proper perspective.

In this chapter we will consider these units again—not as individual instruments but as parts of a system. The system concept is helpful in understanding unit functions, relationship between units, and system operation. Therefore, we will first discuss the individual units of a typical system. Next, we will cover data flow between associated units. And, finally, we will give examples of data flow in complete systems.

The need for rapid handling and evaluation of target data, from detection to destruction, has introduced a system concept beyond the traditional fire control system. Traditionally, the

system of equipment used for the control of a particular battery has been known as a fire control system. The introduction of instruments and entire systems that do not fall directly into this definition has given rise to the term Weapon Control System (WCS). A WCS is defined as a group of interconnected instruments used to control the delivery of effective fire on selected targets. Note how broad this definition is, and how much ground it covers. The definition does not restrict the system as to weapon type; and it includes instruments that are only indirectly involved in weapon control. The WCS is composed of a Weapon Direction System (WDS), and one or more Fire Control Systems (FCS), (fig. 4-1). Some WCSs have a Target Designation System (TDS) in place of the WDS.

WEAPONS DIRECTION SYSTEM

Fundamentally, the WDS or TDS acts as a “clearinghouse” for target information. Early designation and acquisition of targets is a prime

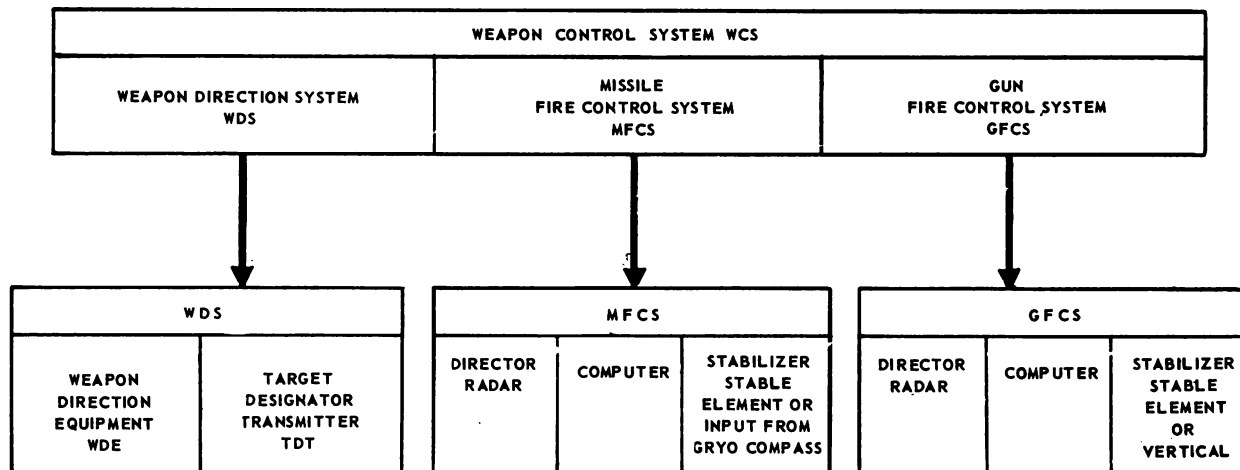


Figure 4-1. —Make-up of a weapon control system.

necessity. This area has been the subject of rapid and continuous development. Originally the systems were called TDSs, and their major components were called Target Designation Equipment (TDE). This equipment's primary function, and in some installations its only function, is target designation to the FCSs. But as the field developed, target designation no longer completely described the equipment's functions, and the name was changed in later systems to Weapon Direction System. In our discussion of a typical system we will use a WDS; but an advanced TDS could be substituted for it.

A WDS consists of Weapon Direction Equipment (WDE) and a Target Designator Transmitter (TDT). The WDE is the connecting link between the search radars and the FCS. The TDT optically detects targets and designates them to the WDE or directly to a GFCS.

It would seem superfluous to describe the functions of the units of a FCS to you. But since we wish to establish a system concept, a brief overview of the FCS's units will help. There are three broad groups of units that make up any FCS;

1. The tracking system which establishes the LOS.
2. The computing system.
3. The weapon drive system which directs the weapons along the LOF.

DIRECTOR

The primary function of both gun and missile directors is to locate and track the target, thereby determining present target position and target motion. Gun directors usually have optical and radar equipment for target detection and tracking. The director is manned, and the crew can readily shift from optical to radar tracking. In the newer FCSs the radar has automatic tracking features, and is an integral part of the director's tracking system. Target tracking may be assisted by aided tracking signals from the computer.

Another function of gun directors is to furnish a centralized control station and a remote firing station for the battery.

Normally, missile directors are not manned, and have no optical tracking equipment. Consequently the second function of gun directors is not present in missile directors. Full radar control is the only type of operation possible.

There are no provisions for local operation in the director, although the radar operation can position the director from the radar console. In both gun and missile directors, the optics and radar antenna are stabilized to a varying degree. Target data are transmitted to the computer.

COMPUTER

The computer relates the LOS to the LOF. It receives tracking data from the director, and has ballistic data built in. The computer generates a prediction angle to compensate for relative motion, ballistics, and errors inherent in the installations. The computer's inputs and outputs depend on the tracking system, type of problem the computer is solving, and type of weapon. There is little to distinguish between the functional units of gun and missile computers. Due to the nature of today's air targets, AA computers are almost fully automatic, with little or no provision for manual operation. The computer may perform data conversion and furnish stabilization quantities for both the director and weapon drive signals. Gun computer outputs of train, elevation, fuze, and parallax orders drive the gun to the predicted position of the LOF. The entire problem of locating the correct LOF is solved before the projectile is fired, with the possible exception of fuze order. In the latter case, when a VT fuze projectile is fired, the proper time for detonation is determined by the fuze itself. Missile computer outputs of launcher train and elevation orders position the launcher in the predicted LOF. This is similar to the gun computer output; however, other orders from the computer go directly to the missile on the launcher. These orders are stored in the missile until needed, and are used in the control of the missile's flight. Corrections to the missile's flight path are applied continuously during missile flight. You might say that part of the FCS is contained in the missile.

STABILIZERS

Directors, gun mounts, and missile launchers are mounted to the deck and measure their position with respect to the deck plane. From this it would seem that the fire control problem could be solved satisfactorily with respect to the common deck plane. But ship's roll and pitch are independent of the target, although

they affect all measurements of target position and motion. Because of this, computers use the stabilized horizontal plane to obtain their solution. To keep the LOS on target, directors, including those with automatic tracking features, are assisted by stabilization. Stabilization is also needed to keep the LOF on an aiming point in space. Thus the three groups that make up a FCS need stabilization. In many systems a stabilizing unit such as the stable element, the stable vertical, or gyro units located in the director furnish stabilization in and across the LOS. The computer performs the necessary coordinate rotation so that the same stabilizing unit can be used to stabilize the LOF. In other installations, ship's roll and pitch are inputs to the FCS. Ship's roll and pitch are not related to the LOS or the LOF, and coordinate rotation is necessary. This may be done within the FC computer or by separate stabilization computers.

CONVERTERS

Each unit in the FCS represents data in a form which is most accurate, economical, and convenient for itself. Data transmitted between units often require conversion to another form. For example, a director may measure target bearing in the deck plane relative to ship's bow, and transmit this information using synchros energized from a 115-volt a-c 60-cycle source. Target bearing data in this form may not be acceptable in other units of the system. The computer may require true target bearing in the horizontal plane. Furthermore, the a-c voltage of 60 cycles may not be acceptable, a d-c or 400-cycle a-c voltage may be required. Data conversion is necessary where a change is made in the coordinate system, reference lines and planes, scale factor, or reference voltage. Data conversion may be accomplished in a section of a major unit such as the director or computer, or it may be accomplished in a separate converter unit.

SYSTEM UNITS

The units will be taken up in the same order as target data are introduced into the system. Only the unit's functional job and pertinent information dealing with its inputs and outputs are considered in this section.

SEARCH RADARS

Search radars detect, locate, and identify targets at long ranges. In this sense we must consider search radars as part of weapons control. Although all search radars perform this job, there are many different types. Since we are concerned mainly with the outputs, we will use them to distinguish between types. Search radars transmit target data to the WDE.

The relationship of the WDE to the search radar is that of a group of remote indicators similar to remote indicators of a fire control radar. The WDE receives from the search radar timing pulses, sweep generating voltages, and video signals. The timing pulses synchronize the WDE's measuring and display circuits with their counterparts in the search radar. Video signals from the radar are amplified and applied to the scopes in a normal manner. There are significant variations between the search radar's and the WDE's methods of defining target's location. The indicating scopes in the WDE are of the PPI type. These scopes use a rectangular coordinate system to orient the display to the surrounding area. Target's position indication in the scopes is determined by the range sweep and the antenna position sweep voltages from the search radar. Since the WDE acts as a precision repeater of the search radar, we will now take a look at the radar's method of defining target position.

The WDE can be connected to receive data from various search radars aboard ship. Normally a radar capable of measuring target location in three coordinates—range, bearing, and elevation—is the primary radar. The radar beam is stabilized, and measures elevation above the horizontal plane. Initially an angular coordinate system is used, with antenna bearing measured relative to ship's bow. The primary radar system includes a computer which converts the radar's angular coordinate system to a rectangular system. The computer also rotates the axes by ship's heading angle to obtain true quantities. For once we don't have to worry about conversion details; it's not our circuit.

The WDE receives from this computer sweep voltages which are proportional to the radar's beam position. The sweep voltages are $V_r \sin E$, $V_r \sin B_y$, and $V_r \cos B_y$, (V_r equals slant range; E , elevation; and B_y , true bearing). These sweep voltages establish the dimensions of the presentation. The slant range, V_r , in the sweep voltages is not target range, but a timed

value indicating the range. This range starts at zero when time is zero, and extends out to the maximum range of the presentation. The search radar's beam and video indications are located within these dimensions. Sweep voltages $V_r \sin B_y$ and $V_r \cos B_y$ are inputs to a PPI presentation used to depict video range and bearing. Sweep voltage $V_r \sin E$ is an input to a target height presentation in a section of the PPI scope. A composite three-dimensional picture is provided within the framework of the sweep voltages.

In case of a casualty to the primary search radar, a secondary source of target information is available from the other search radars. The secondary radars transmit the same basic information, except that they may not measure target height, and the sweep voltages may represent angular coordinate quantities. The WDE converts the angular coordinates to rectangular.

The WDE presentation is normally oriented to the N/S axis. But if ship's heading is not available, a relative picture can be displayed. This is indicated by a warning light. Also if the primary search radar's coordinate computer is not operating, the WDE can perform the necessary coordinate conversion.

WEAPONS DIRECTION EQUIPMENT

The WDE is the link between the search radars, (and in some installations the sonar), and the WCS. Long range search radars detect and identify targets at long range. To successfully repulse an enemy attack, particularly multiple target attacks, many decisions must be made long before the enemy is within firing range.

The defense of a task group or force deals with depth and density. In WW II, task group air defense consisted of Combat Air Patrol (CAP) and ship's guns. The CAP furnished depth to the defense. Gun ranges, and the time available to use the guns against aircraft, were both short. The ships in the task group closed into a tight formation to obtain increased gun density. Today, with improved detection equipment, communication techniques, and weapons particularly the guided missile, defense in depth is employed. The task group is deployed over a large area. Early warning planes and picket ships are stationed at the extreme limits of the operating area. Defense efforts are coordinated under a task group AntiAir Warfare (AAW) command. CIC in each

ship tracks all reported and detected objects. Thus before target video has glowed in your WDE, the AAW command and your ship's CIC evaluator has studied the target's indications and movements. Target evaluation and defense actions have been started before the WDE picks up the target. The WDE is a part of task group defense. Remember this, for we treat the subject here as only ship's defense. Furthermore, we begin evaluation at the WDE. To see the complete picture, it would be helpful to talk to a radarman about CIC's part.

Each target is evaluated as to the threat it imposes. The best suited FCS and weapons to deal with the various targets must be determined. The FCSs must be assisted in the process of acquiring their assigned targets. A continuous appraisal of the tactical situation during the entire operation must be maintained. The length of time available for performing these operations is extremely limited. The WDE centralizes the rapid accomplishment of these tasks and provides supervised and coordinated target evaluation and assignment.

The assignment of a FCS and its associated weapons is based on the evaluation of target threat. This evaluation is in turn based on weapons available, and on the target's capability and probable intent. The weapons are a known factor but only an educated guess can be made as to target capability and intent. The need is to engage the target at sufficient range to obtain a good probability of a kill before the target can accomplish its mission. To do this we would bring the FCSs and weapons to bear on the target as soon as possible. Tactical conditions, however, may not allow the use of certain weapons. In a multiple target attack the threat that each target imposes must be weighed to determine target priority and weapon selection. An estimate is made of the maximum range at which each target can effectively release its weapons. This is called Estimated Weapons Release Range EWRR. Target interception must be beyond EWRR. Each target is given a priority in accordance with his EWRR and the time he will arrive at it. Weapon selection versus target priority is based on the weapon's maximum range and its kill probability. Short range guided missiles and AA guns do not use EWRR directly. Target kill must be at or near maximum weapon range.

The WDE graphically displays the location of targets and tracks selected targets. Target location data are continuously available for

transmission to an assigned FCS. A FCS detecting equipment (optical or radar) searches a small volume of space. An unaided FCS normally experiences some difficulties in acquiring a moving target; but when it is aided by the WDE, the time between target designation and acquisition is greatly reduced.

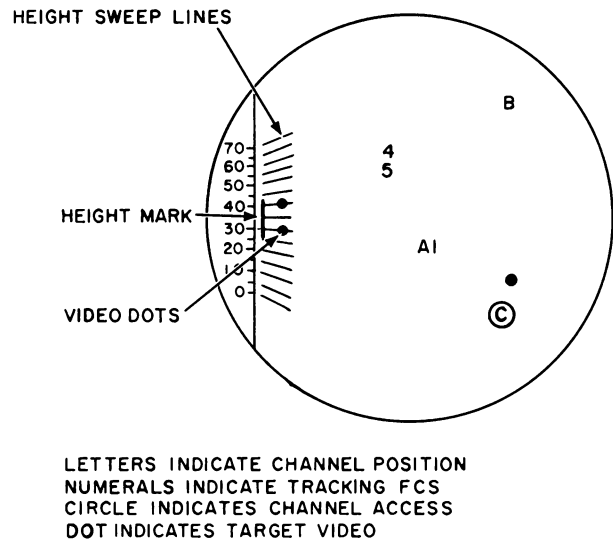
The WDE is designed so that each station in the system performs only a part of the overall system's job. Each partial job is initiated by a preceding act performed in a systematic schedule of events. Thus at each station the operator has only a limited number of decisions to make and a limited job to perform. In this way target data are handled efficiently and with minimum delay.

WDE installations vary; fortunately, however, the major units and their functions are similar. The major operational units are the Target Selection and Tracking Console, the Director Assignment Console, and the Weapons Assignment Console.

Target Selection and Tracking Console

The Target Selection and Tracking Console (TSTC) receives inputs from a search radar and produces a PPI and a target height display. The display depicts the tactical situation about own ship as seen by the search radar, (fig. 4-2). From the display an initial evaluation of target threat is made. The range and bearing coordinates of targets considered threatening are inserted into automatic tracking channels. Successive target position inputs to the channel are used to calculate and correct target's range and bearing rates. The tracking channel provides a continuous generated target position in these quantities. Target height, when measured by a three coordinate search radar or when obtained from another source, is inserted in the tracking channel and memorized. Target height is not automatically generated as a rate-aided quantity but follows the input value. The channels are normally identified by a letter designator. Thus we could have channels A to F. The numerals in figure 4-2 identify tracking FCSs. The positions of targets in the tracking channels are transmitted to the director assignment console. Any target appearing in the equipment after the TSTC is considered hostile or of interest to the ship's FCSs.

Most installations have more than one TSTC. Normally, one console is used primarily for



92.13

Figure 4-2.—Tactical display of target selection and tracking console.

selecting targets and the others for tracking targets. Each console, however, has the same display. By having more than one console the operational burden and the decision-making requirements of each operator are reduced. Remember that when handling target data, time and accuracy are important. Identification of targets is normally handled by CIC, but the TSTCs have IFF challenge controls to permit last-minute identification. In an emergency, a TSTC can designate directly to the FCSs. For this reason the positions of the FCS's directors and clear bearing zone for missile firing are available for display. In normal operation, however, clear bearing zone is not displayed.

Director Assignment Console

The Director Assignment Console (DAC), receives from the TSTC position indications of targets being tracked in the channels (fig. 4-3). All video indications from the search radar are held up in TSTC. Targets' positions in range and bearing are displayed in a PPI presentation. Targets are evaluated, and the best sequence in which to engage them is determined. The best suited weapon, gun or missile, to be employed against each target is automatically selected with the FCS. The FCSs are assigned to targets based on these decisions. Many evaluation aids are displayed to assist in making these decisions.

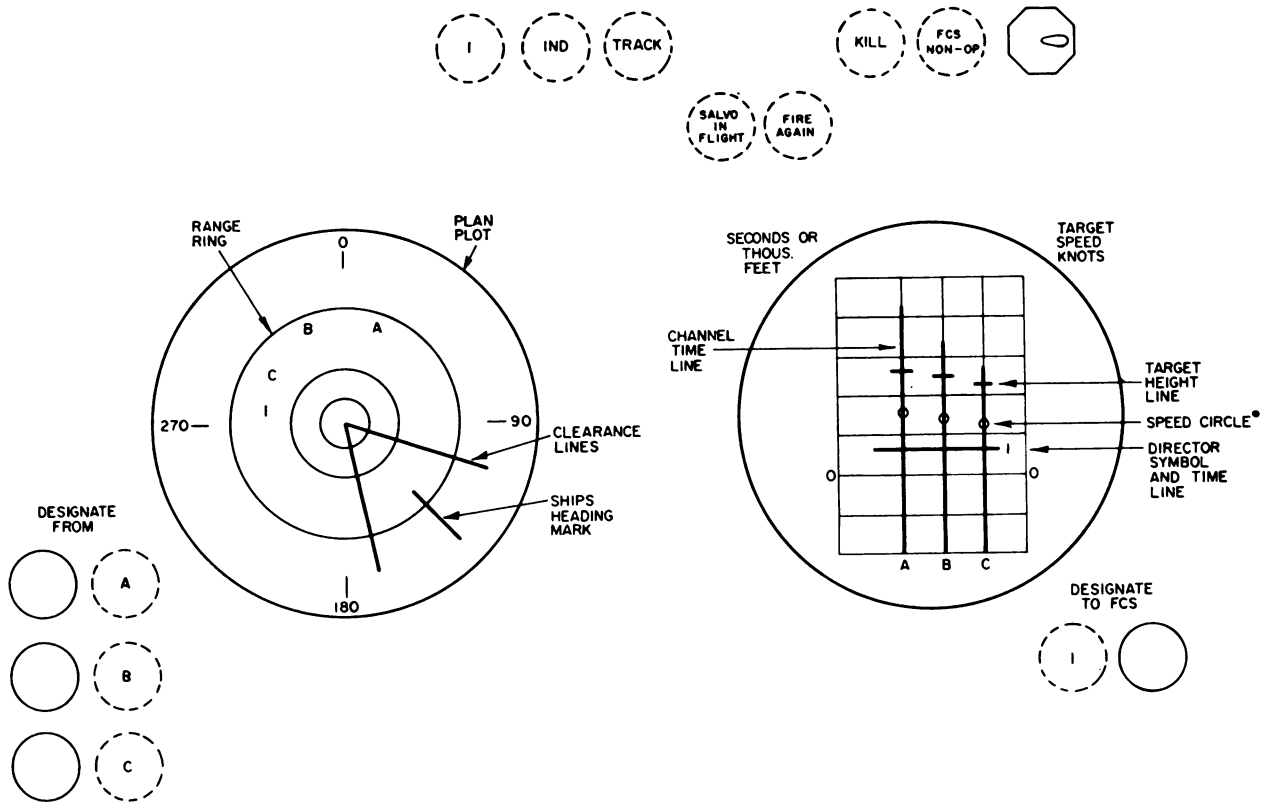


Figure 4-3.—Director Assignment Console Display.

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Target present position as measured by a tracking FCS is provided by repeat-back data. Missile clear firing zones and own ship's heading are displayed. Ship's course changes can be recommended from the DAC. The course and speed of a selected target is available from its tracking channel.

In addition to the evaluation aids displayed in the PPI-scope, another multiple purpose presentation indicates target height, target speed, and time factors for each target in a tracking channel. There are two time values displayed. One indicates the time within which a missile director must be assigned and a missile fired in order to intercept the target before it reaches its EWRR. This time factor is computed considering the time lapse between target designation to a Missile Fire Control System (MFCS), missile firing, and flight to intercept point versus the target's range, speed, and EWRR. The second time factor represents busy time for a MFCS. When the MFCS is in

air-ready mode the indicating line is stationary, representing a fixed value. After the MFCS acquires the target but prior to firing the missile, the line moves to a position which indicates approximate time of flight to intercept. Once the missile is fired, the line moves down the time scale and indicates an approximate time to intercept. Although based on the use of missiles, the time indications can be used to a good approximation with gun systems.

A comparison of the evaluation aids displayed will dictate the correct FCS assignment. Once this decision has been made the assigned FCS is mated to its selected target. The DAC designates the target's coordinates to the FCS. The FCS, upon receiving designation signals, slews from the air-ready position to the designated range, bearing, and elevation. The FCS follows the designated data modified by a search program until it acquires the target. Targets being optically tracked by the TDTs are displayed in the DAC's presentation. These

targets, being relatively close aboard, have priority over all other targets. TDTs can designate directly to a GFCS, although normal operation is for the TDT designation to go through the DAC.

A FCS's view of the tactical conditions is limited to the area in the vicinity of its assigned target. Consequently the MFCS operators are in a poor position to select the type of missile to be fired and its loading on the launcher. The time required to load a missile on the launcher rail and missile warmup limitations makes timing of the loading sequence important. If the MFCS operators are not in a position to control missile loading, then they are not in a position to control missile firing. The selection, loading, and firing of the missiles are controlled in the WDE operations. A conventional AA gun's maximum effective range is relatively short in comparison to that of missiles. Consequently, targets engaged by ship's gun batteries are close aboard and are of immediate concern to ship's defense. There is little time available, and the assignment of guns to a FCS must be prearranged by ship's doctrine. Therefore the assignment of a GFCS by the DAC automatically includes the gun mounts associated with the system. The conditions which require missile selection, loading, and firing to be a function of the WDE are not present in gun fire. Thus the GFCS controls the entire procedure once the order to commence fire is given. This phase of WDE operation deals only with missile batteries.

Weapon Assignment Console

The Weapon Assignment Console (WAC), has two identical PPI-scopes. Each scope displays elements of the problem being solved by a MFCS (fig. 4-4). The information in this phase of the WDE operation deals only with targets being tracked by a MFCS. The tactical information has been reduced to the minimum essentials necessary for the WAC operator to make the final evaluation of the targets. The WAC normally works in conjunction with a missile launcher and two MFCSs which share the launcher. Target evaluation is made in terms of:

1. The possibility of missile intercept. This deals with the type of missile selected and its capabilities.
2. Missile assignment. This deals with target precedence—which of the targets being tracked is the most threatening.

3. Launcher clearance. This determines if the missile launcher is in a clear firing zone for each target.

To assist the operator in making the final evaluation, each PPI presentation displays ship's heading and launcher clear firing zone. If a course change has been recommended the operator can shift his presentation to the ordered course and obtain a preview of the situation on the heading. While a MFCS is tracking a target, the following indications aid in evaluation.

1. Target present position as measured by the MFCS.

2. Target course.

3. Target predicted position at intercept point if the missile is fired as soon as the launcher is ready. This comes from the FC computer. The WAC operator can insert a delay time into the problem. The computer will then transmit an indication of target predicted position at the end of the delay time. This allows the WAC operator to project the problem into the future. (Targets course and speed are assumed to be constant during delay time.)

4. Maximum missile range at target's predicted altitude at intercept. This value is determined by the target's course, speed, and altitude. An approximate minimum missile range is also indicated. The distance between the maximum and minimum ranges indicate the effective range of the missile for this target.

5. Launcher bearing received from the launcher train unit. This indication is used in conjunction with the launcher clear firing zone. In some short range missile systems launcher bearing is not displayed.

Based on target evaluation the launcher is assigned to a MFCS. Launcher missile loading orders are originated and the missile is fired from the WAC. A Launcher Status Indicator is provided to facilitate making the loading orders. As the name implies, the indicator summarizes the status and the type of missiles loaded on the launcher, and those available in the missile feeder system. This information is relayed to the WAC. When the predicted intercept point of a selected target is within the missile's range, the WAC operator is free to fire the missile if ordered to do so.

WEAPON DIRECTION EQUIPMENT OPERATION

Figure 4-5 shows the flow of basic quantities in the equipment. The flow diagram is simplified so that the operational relationship between the

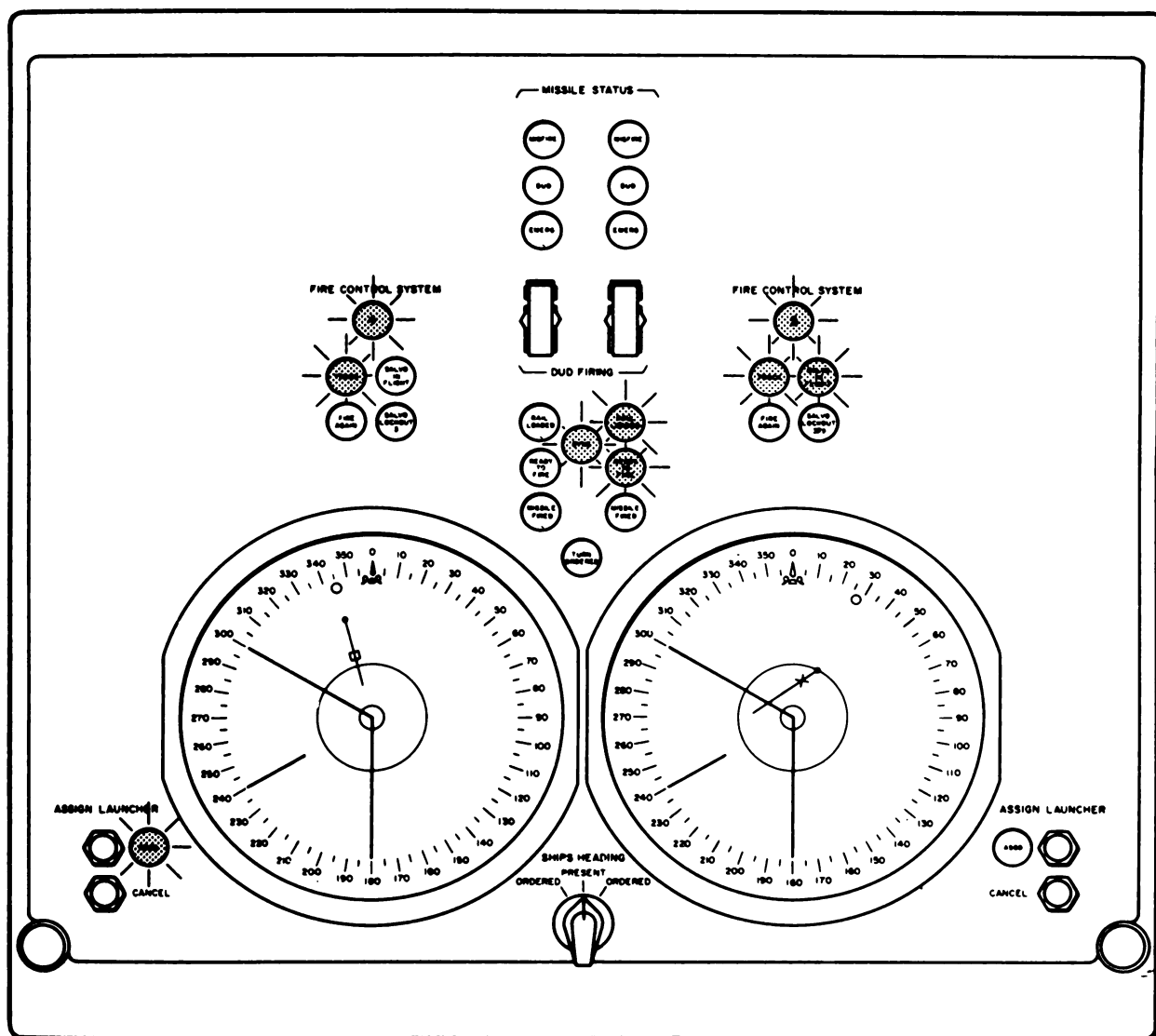


Figure 4-4.—Display at Weapon Assignment Console.

92.14

major units can be more easily understood. Most of the auxiliary equipment is not shown. The computation or generation of quantities is not shown or explained. This will be covered in a chapter on this equipment. Coordinate conversion is not considered in this diagram. Coordinate conversion in a typical system will be shown in a separate figure.

Basically we can divide the operation of the system into three distinct phases. Each phase is performed at a major unit of the system. Your installation may consist of one or more of these units.

Phase I

The initial source of target information is normally from the search radar. Inputs from the radar (fig. 4-5), go to three TSTCs. These consoles have identical displays. At TSTC number 1, targets to be tracked are selected and assigned to channels. TSTCs 2 and 3 are target tracking consoles.

The operators of the tracking consoles track the targets in the channels. The channels are designed by letters and are divided between

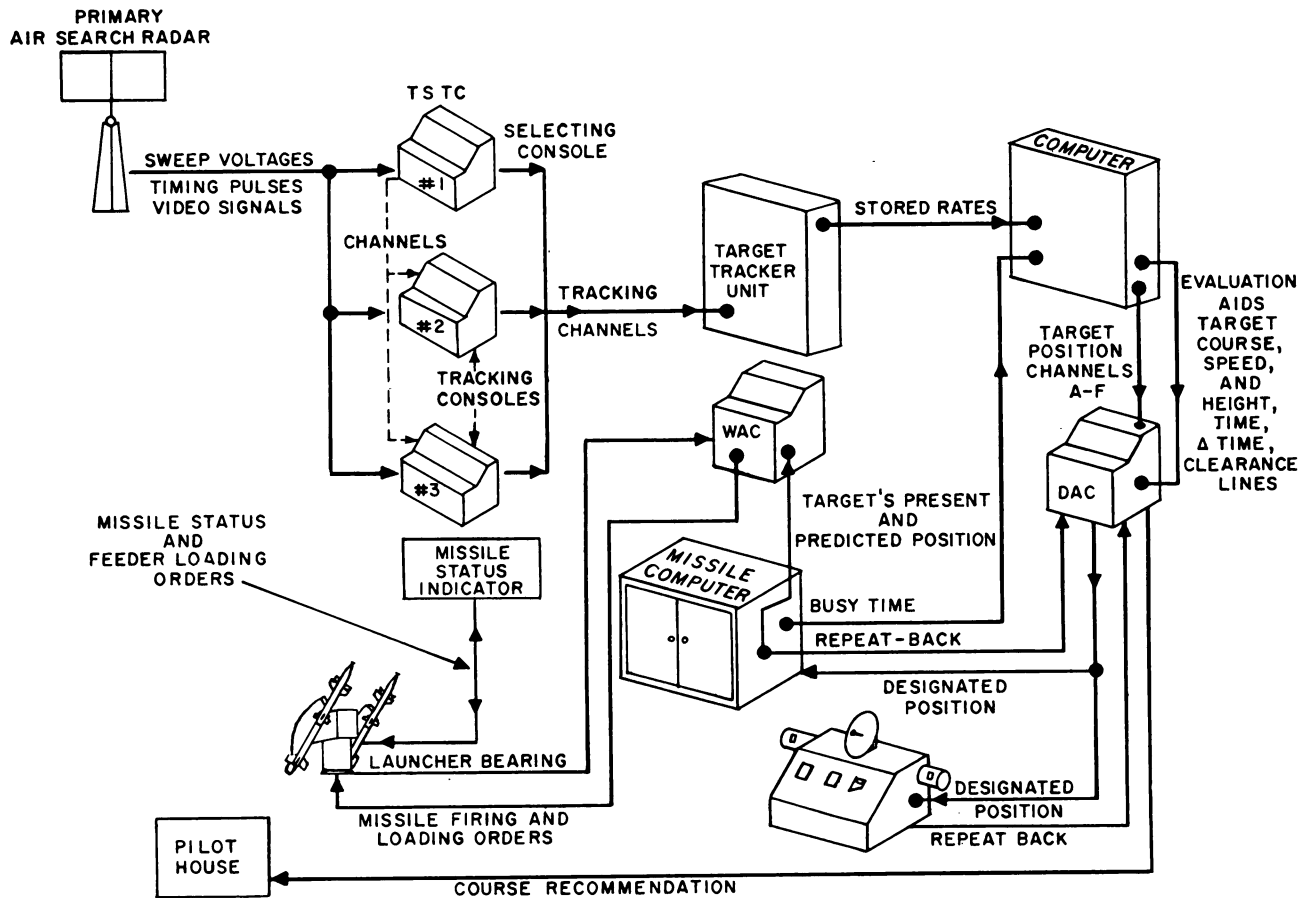


Figure 4-5.—Basic designation data flow.

63.19

the tracking consoles. A pantograph arm measures target's position with relation to the display. When the arm is positioned over target video and a rate-aid switch pressed, target position data are inserted into the tracking channel. Successive changes of pantograph position are compared with previous positions and a target rate is the eventual result. The continuous rate-aided solution will then keep the channel letter designator positioned on target. Only three or four pantograph corrections should be needed to establish a fairly accurate rate.

A tracking operator can insert target data into a channel only if he has access to that channel. Access to a channel can be gained through a switch on the pantograph arm or by pressing the desired channel pushbutton. Channel access is electronically indicated by the presence of a small circle around the channel letter designator. To put height into a channel, the operator gains access, rotates a height cursor knob to align a height measuring spot

on the scope to the target's height video indication, and then operates a "height data in" switch. If a 3-coordinate radar is unavailable but height is known, the same procedure is used except now the known value is inserted. If height is estimated, the operator throws a switch that energizes the "elevation unreliable" circuits. These circuits change the search pattern of the FCSS. Control indicators (panels) are used by the console operators to insert EWRR into the system. Provision has been made in the control indicator for missile-in-flight destruction. The missile destruct switches are thrown when the missile goes awry or when friendly forces are endangered.

Phase II

The positions of the targets in the tracking channels are transmitted to the DAC continuously. The console operator evaluates the targets, using the many aids displayed. Based

on this evaluation the operator assigns FCSs to the targets. Pushbuttons on the left side of the console are used to "designate from" a target data source. The source may be any one of the tracking channels, one of the optical target designation transmitters (TDT), or one of the AA directors which has previously acquired the target. Designating from a director to another director is called inter-director designation; it is by far the most expeditious method, since the target is more accurately pinpointed by fire control radar.

Pushbuttons on the right side of the console are used to "designate to" a FCS. There is a pushbutton for each director, arranged in numerical order from top to bottom on the console.

To assign a director to a target data source, the console operator merely presses a "designate from" simultaneously with a "designate to" pushbutton. For example, if we wish director 5 to track the target in channel C, we would depress the C in the "designate from" column and the 5 in the "designate to" column, simultaneously. If we want director 5 to track director 2's target, we would depress the 2 in "designate from" along with the 5 in "designate to".

Circuits are then activated which automatically slews the director to the target in range, bearing, and elevation. Remember, the accuracy of the elevation information depends on the reliability of target height data. Range and bearing accuracy depend primarily on the tracking ability of the target selection and tracking console operator.

A director is released from the designation mode of operation when it acquires the target with its own equipment, or when the DAC operator presses a designation "release" pushbutton on the right side of the console. The "release" pushbutton will have to be depressed at the same time as the director's "designation to" pushbutton.

A tracking channel is "dumped" by using more or less the same procedure. Another release button, on the lower left of the console, must be depressed simultaneously with the pushbutton for the channel that is no longer desired. A tracking channel can also be dumped at the target selection and tracking consoles by using the same procedure; however, a good practice would be to dump channels only from the director assignment console. Undesirable director acceleration may result if a channel is dumped when the director is

attempting to acquire the target. For this reason it seems advisable to dump channels from the DAC, since it is the only console where director acquisition of the target can be viewed. The director's number is not present on the target selection and tracking consoles until the director shifts into the track mode.

UNMASKING THE BATTERY.—An ever-present problem in weaponry is the limitation placed upon firing arcs by the ship's superstructure. For obvious reasons, launchers and guns are electrically cut out if they are aimed at any part of the ship. The cutout area in bearing and elevation is referred to as the blind zone for a specific weapon. An after launcher cannot fire dead ahead, and a forward gun is cut out directly aft. The DAC operator solves this problem by making course recommendations to the pilot house. To recommend a course the operator rotates a "course recommend" knob to the desired course and activates a "course recmd" switch. The recommended course is indicated in the pilot house. Maximum fire power will be brought to bear if the ship places her beam to the expected attack; however, this is not always feasible. If the new course would endanger the ship, the officer of the deck will intercede. The DAC operator recommends a course change as soon as the target's projected track indicates that it will enter the blind zone.

Phase III

Launcher assignment is made at the Weapon Assignment Console. The WAC operator has control over all factors involving the selection of a particular type of missile and its subsequent loading. In addition to this control of the missile loading operation, the WAC operator fires the missile from a firing key located at the lower right of the console. The time of missile firing is very important, since we must strive for missile intercept before the target reaches his weapon release point. Missiles are usually fired so as to intercept the target at maximum missile range.

Surface-to-air missiles in use today require a certain warmup period before they are ready to go. Yet a prolonged application of power may cause damage, or upset the electronic balance because of the heat generated within the missile. This means that the missile cannot be energized

well in advance of the expected launch. Consequently, the WAC operator must make a judgment as to the time to commence missile warmup.

The weapon assignment console on our ship is designed to operate with two missile directors and one launcher. The launcher has two missile launching rails which are labeled A and B. The launcher cannot be controlled simultaneously from both director systems. If both directors have targets to be fired upon, the launcher will be alternately switched between directors. The switching process may continue if multiple salvos have been ordered for both directors.

The weapon assignment console has two identical sections. The left side is for one director, the right side for the other. Each side has a radarscope display. A target is presented on the scope as an illuminated dot if the director is tracking. A line extending from the target dot indicates the direction of the target's course. Somewhere along this line is a small square or cross which indicates the intercept point. The intercept point represents a calculation of target speed, target course, and the delay in getting the missile ready. A large electronic ellipse shows maximum missile range with respect to the target being tracked. The missile is fired, provided it is ready when the intercept point is within the ellipse. A small circle around the center of the display represents the approximate minimum range of the missile.

A small circle at the outer edge of the scope indicates the predicted true launcher bearing at firing time. The position of the predicted launcher bearing circle is particularly important if the launcher is approaching the firing cutout limits. Speaking of firing cutout limits, the WAC operator sees just about the same thing as the DAC operator in regard to blind zones. If a turn has been recommended, the WAC operator can project the proposed course onto the firing director scope to see what effect it will have on the launcher. He does this by shifting a "ship's heading" switch from "present" to "ordered" for the firing director's scope.

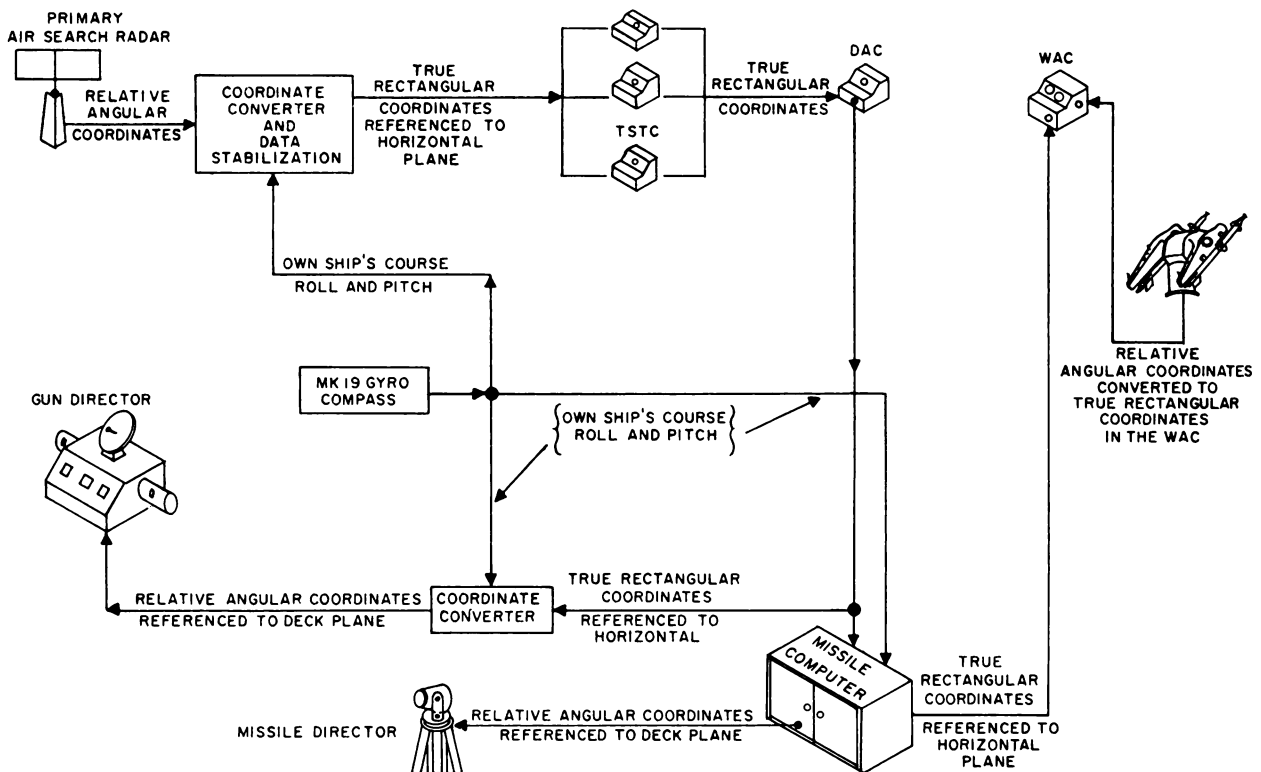
Launcher assignment to a FCS is made after a missile has been loaded onto a launcher rail. This is done at the WAC by depressing an "assign launcher" pushbutton for the desired director. There is also a "cancel" button for each director in case reassignment is desired.

Operation of a "salvo select" switch determines whether two missiles are to be fired in one salvo or a single missile from either rail. Missiles in a two-missile salvo do not go at exactly the same time, as there is a slight electrical firing delay to avoid in-flight interference.

We mentioned that the launcher is assigned after it is loaded, and that launcher loading is the responsibility of the WAC operator. There are many lamps located on the WAC and a unit called the guided missile status indicator to assist the operator. The lamps at the WAC are used primarily to indicate the firing and operational status of the system. Some of the data they present are director track, launcher rail loaded, launcher assigned, launcher synchronized, ready to fire, missile fired, salvo in flight, and fire again. The main functions of the missile status indicator are to provide a means for selecting the type of missile and to indicate the progress of each missile in the loading sequence.

COORDINATE SYSTEMS

Coordinate systems and coordinate conversion were purposely ignored when we discussed data flow in the WDE. Fortunately the coordinate system used in a particular piece or section of the WDE is standard. Thus by knowing the coordinate system used in a piece of equipment we can determine from its inputs if coordinate conversion is required. Figure 4-6 shows the coordinate system of the data flow in a typical system. Let's start at the search radar. The primary search radar measures target position in three coordinates. The measurements are made using relative polar coordinates stabilized in elevation. Initial values are slant range, relative bearing in the deck plane, and elevation measured above the horizontal plane. A coordinate converter is included in this radar system. The converter's outputs are true rectangular coordinates of N/S, E/W slant range referenced to the horizontal plane, and height which is equal to the sine of the elevation angle times slant range. This is the coordinate system used in the target selection and tracking consoles and the director assignment console of the WDE. Secondary search radar's outputs to the WDE are in polar coordinate form. Conversion to rectangular coordinates is accomplished in the WDE before the information is displayed.



63.20

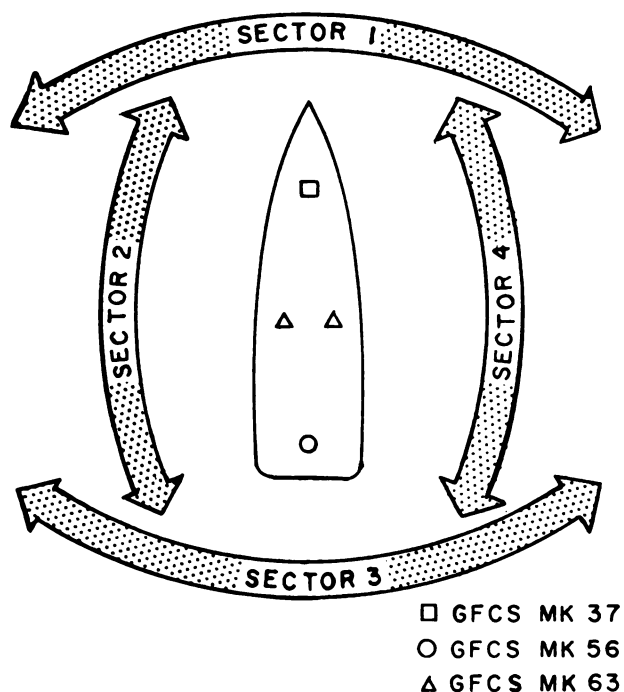
Figure 4-6. —Coordinate conversion in the WCS.

The DAC transmits designation data to the FCS. The target detection units of the FCS are its director and radar. These units use a relative polar coordinate system referenced to the deck plane. Because of the many types of FCS, the units which perform the required conversion between the DAC and the director vary. A separate coordinate converter is normally installed as part of the WDE for the necessary conversion between GFCS's directors and the DAC. This is also true of some MFCSS. But in some of the MFCSS the missile computer performs the conversion. Generally, if the FC computer solves the relative motion problem using the rectangular coordinate system, it performs the conversion.

The WAC uses the rectangular coordinate system, and works in conjunction with the missile systems. The same general rule applies in the WAC as in the DAC. If the missile computer uses the rectangular coordinate system to solve the relative motion problem, it will perform the conversion. Otherwise coordinate converters are installed as part of the WDE.

TARGET DESIGNATION SYSTEMS

The major units of the TDE in ships with gun and missile systems are identical to their counterparts in the WDE. But the TDE used in ships with only conventional AA guns installed are much simpler. Due to the limitation of AA guns, particularly their range limits, there is no need for target evaluation or FCS assignment to be phased into stages as in the WDE. Normal procedure is to commence fire as soon as a target is within effective gun range. Consequently, each gun battery opens fire when the target enters its range band. In a single target attack, gun range is the governing factor. To ensure maximum coverage in a multiple target attack, each GFCS and its associated gun mounts protects an arc about own ship. As an example of this factor we will use a DD with a GFCS Mk 37 forward, a Mk 56 system aft, and a Mk 63 system on each beam, (fig. 4-7). The 37 system has control of the forward 5° gun mounts, and is responsible for arc 1 in the diagram. The 56 system is dual ballistic and



92.15

Figure 4-7.—Sector assignment of AA battery.

has control of the after 5" and 3" gun mounts. This group is responsible for arc 3. Each 63 system controls a 3" gun mount. These groups are responsible for arcs 2 and 4. Naturally the mounts controlled by a GFCS and the area responsibility of the group are flexible. Both factors depend on the tactical situation and a prearranged ship's doctrine.

Target evaluation in gun systems considers target's location in relation to the ship, range, closing rate, and gun range. The assignment of a GFCS to the target is based on these factors.

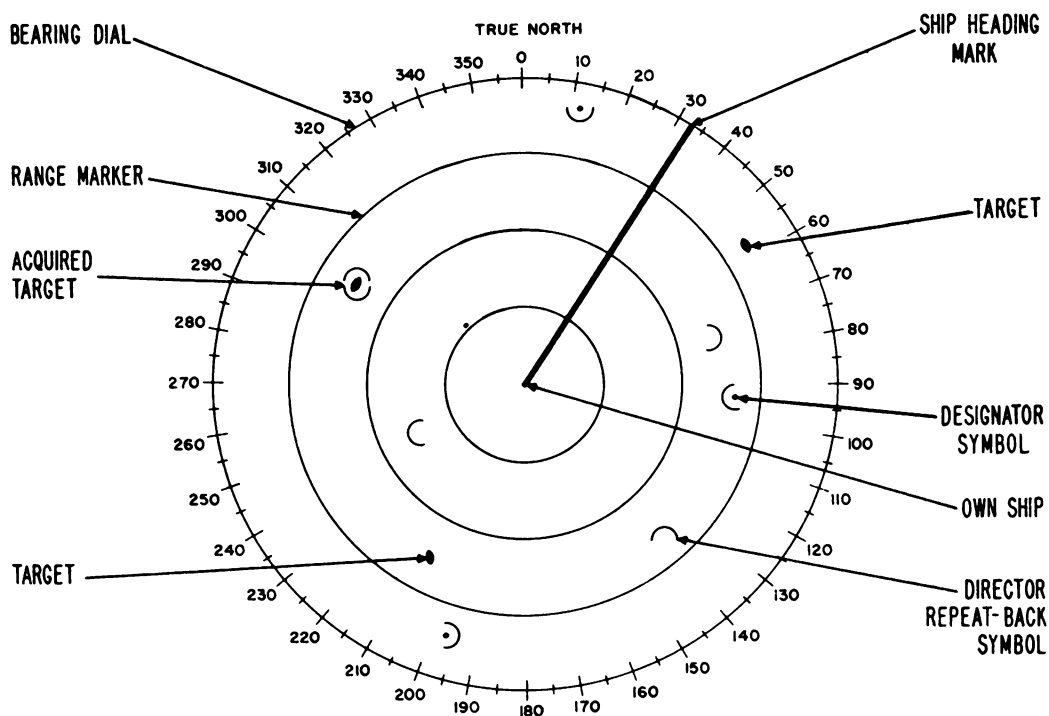
A TDE extensively used has an "all purpose" console to evaluate, track, and assign targets. The console has a PPI presentation which uses a rectangular coordinate system referenced to true north. Sweeps voltages from the search radar represent a polar coordinate system referenced to own ship's bow. Coordinate conversion and axes rotation are accomplished in the TDE. The presentation is unstabilized, referenced to the deck plane. Video indications of a target are displayed in N/S and E/W ranges. Elevation is not displayed in the console, since search radars in the installations with this type of TDE are usually not capable of accurately measuring elevation.

Targets are evaluated and assigned to one of the console operators. There are four operators, each assigned to a tracking channel of the TDE, which in turn is connected to the designation circuits of a GFCS. The operator manually tracks his target by inserting the target coordinates into the channel. Automatic tracking by rate-aided generation or automatic position inserts is not provided. The operator controls the position of a hook symbol in the display (fig. 4-8). When the target video indication is within the hook, the correct E/W—N/S coordinates defining target position are in the tracking channel. To designate target position to the GFCS, the coordinate system must be converted to relative polar coordinates. This is accomplished in the TDE. Range and relative bearing designation signals are transmitted to the GFCS. The director/radar is driven to these values. Elevation in this TDE installation is not designated. Director elevation is driven to a low angle value by a fixed signal originated within the GFCS. (In the beginning of the designation problem, ranges are relatively large and the target is just over the director's horizon. Therefore initial target detection will be at a low angle of elevation.) The GFCS commences a search for the target in the designated area. Repeat-back information in range and bearing of the director position is returned to the TDE. Coordinate conversion is again necessary. Director position is displayed in the PPI-scope as a hook. When the director is synchronized with the designation signals the director hook joins the channel hook. The combination of the two hooks encircles the target video indication.

When the director has acquired the target in its optical or radar equipment, the TDE has completed its job with respect to this target and GFCS. If the director loses the target, the TDE can redesignate it to the director or for tactical reasons the TDE may reassign the director to another target.

TYPICAL GUN FIRE CONTROL SYSTEMS

The purpose of this discussion is to help you understand the operations of gun fire control systems—the relationship between the component parts and the method used in each system to solve the fire control problem. We will use the GFCS Mk 37 and Mk 56 as examples. The symbols representing fire control quantities



92.16

Figure 4-8.—TDE console display.

are those found in the system OPs. In some cases these symbols vary from the symbol system outlined in OP 1700, Vol. I.

GUN FIRE CONTROL SYSTEM MK 37

The Mk 37 director system, in its various modifications, is designed for the primary control of 5"/38's and 5"/54's against either aerial or surface targets. At short ranges, the system can be used for the secondary control of 3"/50 and 40-mm guns. The system also controls the illumination of a surface target with star shells.

The Mk 37 director, Mk 1A computer, and Mk 6 stable element are the main components of the system. They are tied together, and to the fire control radar, bridge, combat information center, star-shell computer, ship gyro compass, pitometer log, and target designation system, by a variety of telephone, electrical, and mechanical connections.

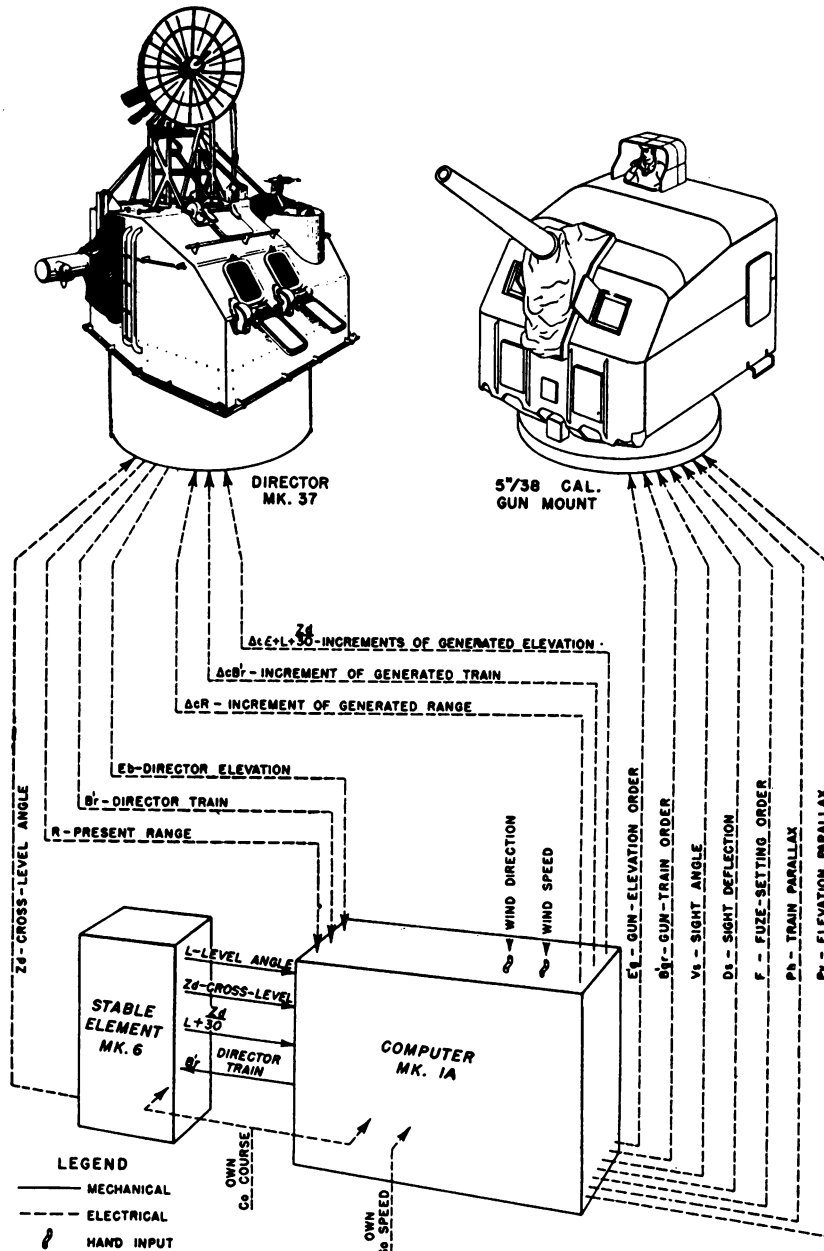
The director furnishes target position information and is the control unit of the system. The stable element supplies the corrections for the roll and pitch of the ship. The computer—as

the mechanical brain of the system—receives this information, computes, and transmits the gun orders required to keep the guns pointed at the predicted position of the target.

THE FLOW OF INFORMATION

The principal connections between the director, computer, stable element, and guns are shown in figure 4-9. Most of the electrical connections are made through the fire control switchboard.

The director measures director elevation E_b , director train $B'r$, and present range R , and transmits these values electrically to the computer. Spot transmitters in the director provide electrical transmission of elevation V_j , deflection D_j , and range R_j spots to the computer. The stable element supplies all of the following mechanically to the computer; level L , cross-level Z_d , and $L+Z_d/30$. Z_d is also transmitted electrically from the stable element to the director to stabilize the optical units and radar in cross level. The stable element receives director train $B'r$ mechanically from the computer, and own ship's course C_o electrically from the gyro compass.



53.114

Figure 4-9. —Data flow in the GFCS Mk 37.

The computer solves both the anti-aircraft problem and the surface problem. Inputs to the computer are electrical from the director, ship gyro compass, and pitometer log; mechanical from the stable element; and manual from the computer operators.

The quantities computed and transmitted electrically to the guns are: gun-elevation order

E'g, gun-train order B'g, sight angle Vs, sight deflection Ds, fuze-setting order F, train parallax for a 100-yard horizontal base Ph, and, on carriers, elevation parallax for a 100-yard horizontal base Pv.

The computer generates changes in range, elevation, and train for the director. These changes are used in conjunction with level and

crosslevel angles to hold the director telescopes, rangefinder, and radar on target automatically when the computer has a solution.

The flow of information for illumination of the target will be taken up when we study the star-shell computer.

THE MK 37 DIRECTOR

Although the Mk 37 director has many modifications, basically it consists of a slew sight, two director telescopes, a rangefinder, and the radar. The slew sight permits rapid target acquisition, while the optical system and radar establish target position in terms of director train, director elevation, and present range. These instruments, together with numerous others, are mounted on a carriage weldment and are enclosed by the shield as shown in figure 4-10.

The director, with its control mechanisms and cable tube, rotates on a base ring and roller assembly that is supported by a barrette built into the ship's structure. The barrette (also shown in fig. 4-10) is machined parallel to the mean plane of the gun roller paths to reduce roller-path corrections to a minimum.

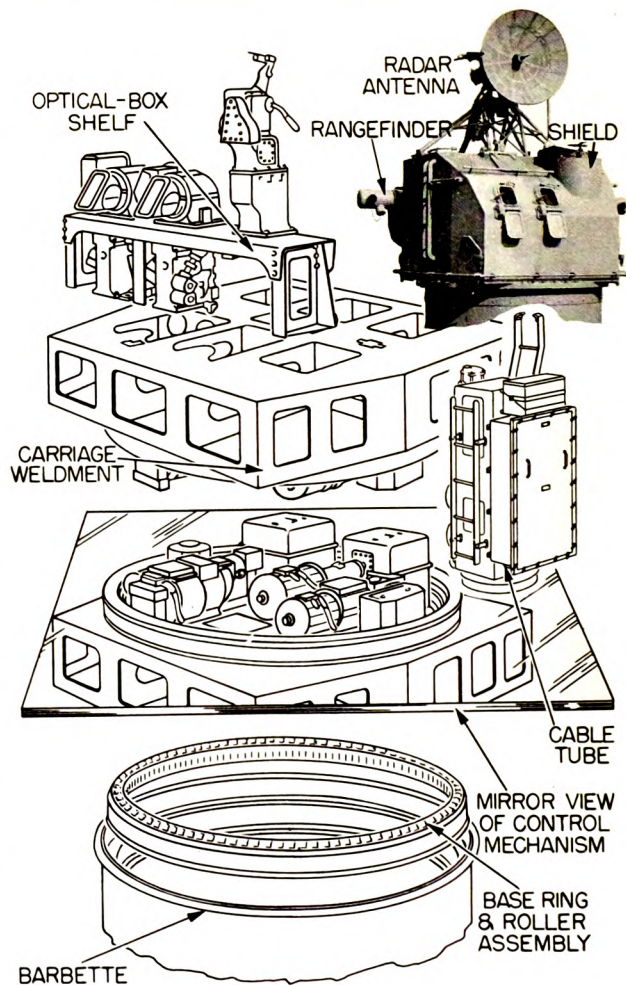
The director optics are mounted with their lines of sight parallel to each other in both train and elevation. The telescopes cannot be trained, elevated, or depressed, as they are mounted in optical boxes that are rigidly secured to the optical shelf.

Thus the entire director is rotated to place the LOS on target in train. In elevation, the LOS of the telescopes is elevated or depressed by rotation of a small prism inside the telescope. The elevation gearing moves the lines of sight of the director telescopes, the rangefinder, and the radar antenna simultaneously and in parallelism, as shown in figure 4-11.

The optics and radar antenna of the director are stabilized in cross-level by the input of Zd from the stable element. Stabilization of the LOS keeps the elevation axes of the director optics and radar antenna in the horizontal plane.

The Director Crew

The director is normally manned by a crew of six (fig. 4-12). Under certain conditions a seventh station is occupied by a control officer's telephone talker. The control officer is in charge of the entire FCS. His battle orders are transmitted to the plotting room and gun mounts to



3.124

Figure 4-10.—Basic components of the Mk 37 director.

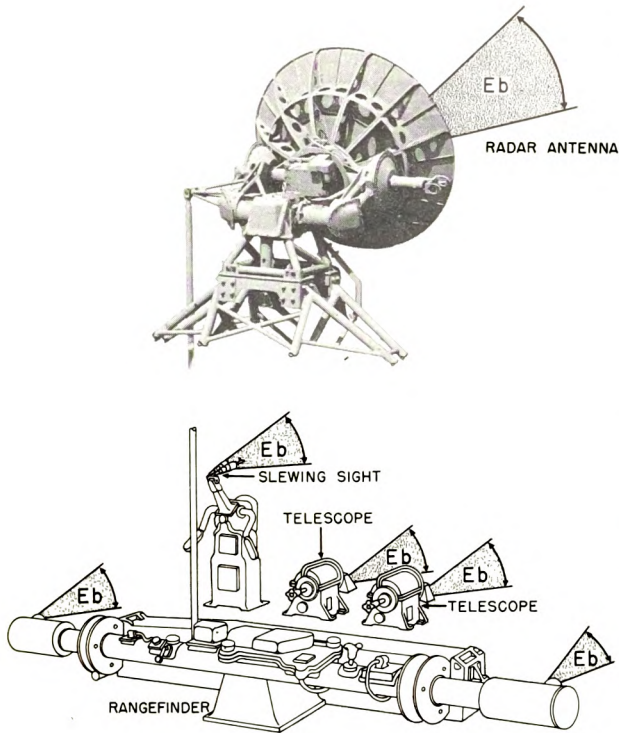
assure effective and coordinated control of the battery's fire power. He is in communication with the weapon control station. From this station he receives data as to a selected target and orders as to when and how the guns are to be fired. Once a target has been designated and firing orders received, it is the control officer's direct responsibility to carry out the orders.

One of the qualifications for advancement to FTC is the ability to stand a control officer's watch. This entails an intimate knowledge of the operational procedures and the functional job of all the stations and equipment in the battery, plus a knowledge of the relationship and interconnections between the battery and other weapon stations. Since the control officer may act as spotter, he must be familiar with the

ship's spotting doctrine. The assistant control officer aids the control officer and is in charge of illumination fire.

The director is equipped to measure target range, bearing, and elevation by means of radar or optical equipment. In full radar control the trainer, pointer, and radar operator, (range), measure target's position by use of the radar. In partial radar control, train and elevation are measured by means of the telescopes while range is measured by radar. In optical control, train and elevation are measured by the telescopes and range is measured by the rangefinder.

The director can be moved in train and elevation in any one of three types of controls; manual, local, or automatic. Selection of the type of control is made by a shift lever at the trainer's and pointer's stations (fig. 4-12). In manual control the power drives are deenergized. The director is moved by direct gearing from the handwheels. In local control the power drives are energized. The director is moved by signals from the pointer's and trainer's handwheels which are now geared to a synchro control transformer in their respective power drives. At the same time, the stator winding of the synchro control transformer is energized from a local supply transformer through a selector switch which is operated by the shift lever.



92.17

Figure 4-11.—The lines of sight elevate in synchronism.

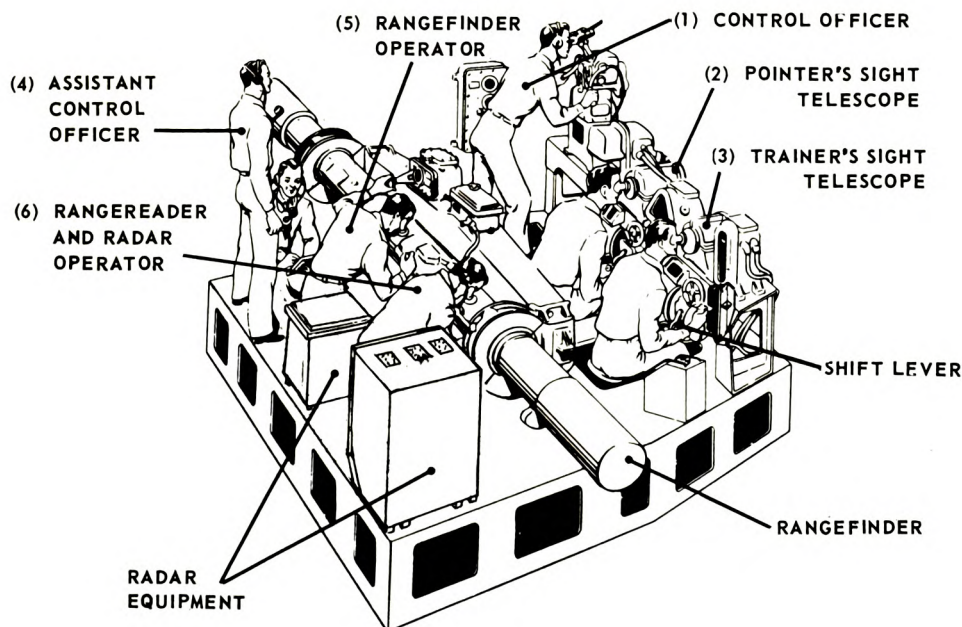


Figure 4-12.—Mk 37 director crew.

53.104

As the trainer, for example, turns the handwheels, he mechanically positions the stator of a CT, causing it to generate an error signal in the rotor windings. This error signal is amplified by the amplidyne system and controls the train power motor. The output of the power motor drives the director in train, and feeds back to mechanically reposition the rotor of the synchro control transformer. This turns the rotor of a set of 1- and 36-speed synchro generators that transmit B'r to the computer.

In some installations the control officer can slew the director in local. When he moves the slew sight he simultaneously closes a key (on the handle bars) that actuates a slewing motor. The slewing motor adds a mechanical signal (proportional to the offset of the slew sight) to the handwheel signal in a mechanical differential. The combination of these two signals turns the stator of the syncho control transformer.

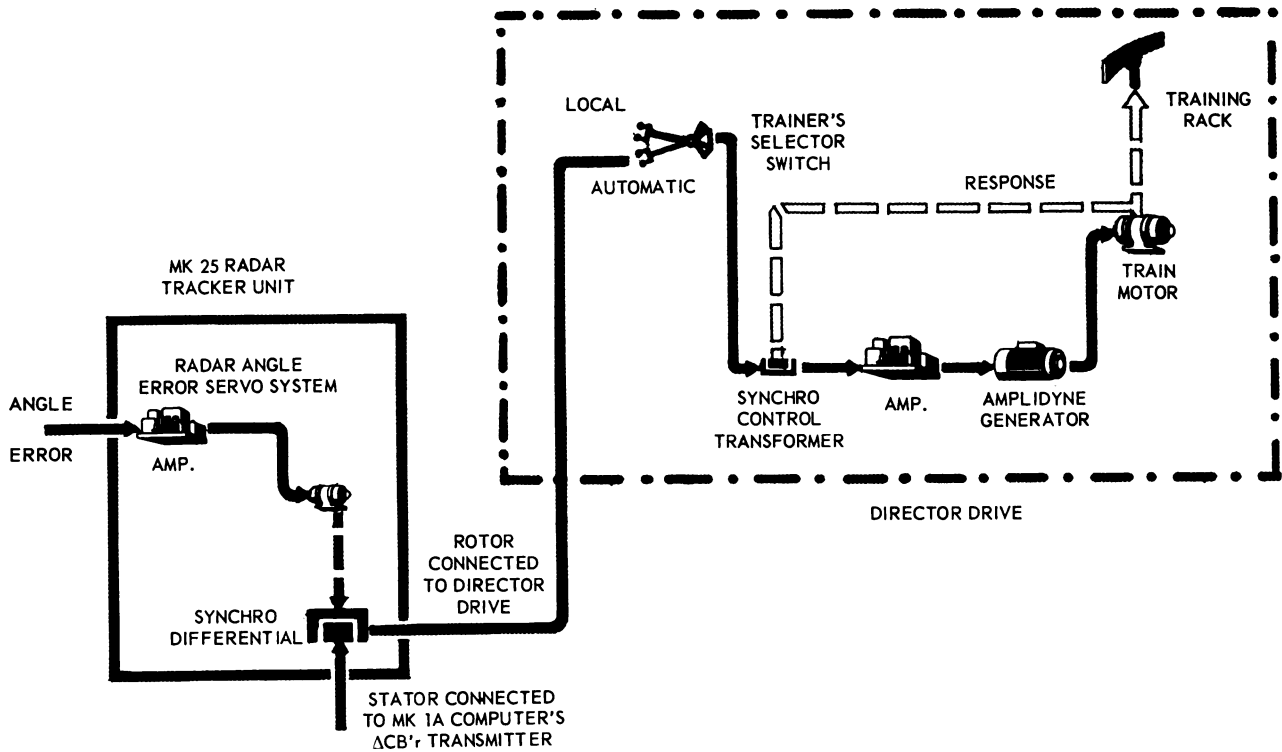
Automatic operation—the most important and the primary method of control—is selected by placing the shifting lever to automatic. The shift lever operates the selector switch to establish the electric circuits for normal (automatic) control. The local power is disconnected from the stator of the control transformer. The stator is connected to receive signals from a remote source. The remote order signal comes directly from synchro differentials in the Mk 25 radar (fig. 4-13). During target tracking, the stator of the synchro differential receives aided tracking signals from the computer. The rotor of the synchro differential is mechanically moved by the radar's angle error servosystem. The electrical output from the rotor is transmitted to the CT in the director drive. The synchro differential output is the algebraic sum of the computer's aided tracking signal and the radar's angular displacement error signal. This arrangement allows the computer's relative motion solution to continuously drive the director to keep the LOS, (established by either the telescopes or the radar) on target. In full radar control, the radar's angle error detector detects position errors caused by a faulty computer solution and modifies the computer's aided tracking signal by rotating the rotor of the synchro differential. The signal modifier is proportional to target's angular displacement from the boresight axis of the radar antenna, and causes the director to accelerate or decelerate. In the computer, the generated and observed target position values are continuously compared. The differences between the generated and observed values

are used in the rate control mechanisms to adjust the generated rate of change to match the actual rate of change. This process continues until the relative motion solution is correct, at which time the director, hence the LOS, will remain on target, being driven principally by aided tracking signals from the computer.

Basically, both train and elevation have two closed loop servosystems which work together to keep the director on target. One servosystem, containing the radar, detects position error by measuring target displacement from the LOS. The other servosystem, containing the computer, detects position error by comparing observed target position with the computer's generated target position. Both servosystems have the synchro differential, the director drive, and the LOS in common.

If the director is in partial radar control or in optical control, the trainer and pointer use their telescopes to establish the LOS. The computer servosystem's operation remains the same as in full radar control. The generated changes are transmitted to the synchro differentials in the radar, and from them to the director drives. These signals are not corrected by the radar, since we are not using the radar's angle tracker. Thus the rotors of the synchro differentials are stationary.

Comparison between the ordered rates of director movement (computer's generation signals), and the correct observed rates of director movement is made optically by the trainer and pointer. Corrections to the generated values are made in the director drive at the control transformer. As the optics tend to drift off the target due to a faulty computer solution the trainer, for example, rotates his handwheels. The handwheels are mechanically geared to the stator of the CT in the train drive. Thus the handwheel signal is superimposed on the generated signal which is the electrical input to the CT. The trainer continues to rotate his handwheels to maintain the LOS on target. But this is a position correction only, and will not correct the target's computed course and speed. To correct the target's course and speed upon which the rates of director movement are based, the trainer closes his rate control key on the left handwheel. This activates circuits in the computer's rate control system. Normal operation in partial radar or optical control is to keep the telescope cross wires on target by turning the handwheels, and to keep the key closed.



92.18

Figure 4-13.—Simplified automatic signal path.

The slew sight is energized in automatic control. Thus the control officer can slew the director even though a target is being tracked. Obviously this should not be done without warning. Plot should cease tracking and the gun mount's power drives should be shifted to local control prior to slewing.

In multiple director installations, where the Mk 37 director is not the reference, a train parallax correction is necessary. Unit parallax from the computer is received in the director's train receiver regulator. The parallax servosystem drives unit parallax through change gears into the train system. The change gears reduce unit parallax to a value proportional to the horizontal distance of the director from the reference point. Since the director is the source of target bearing, its actual position is not changed by parallax as is a gun mount. Only the indicating dials and synchro transmitters are affected by parallax.

In full or partial radar control the radar is the source of target range, and in optical control the rangefinder is the source. A selector switch in the rear of the director determines from which instrument range is transmitted to the computer.

Generated range changes are received from the computer to aid in staying on target. The rangefinder's range measurement is intermittent. Therefore the computer's automatic range receiver servosystem is deenergized when the rangefinder is used. Range is inserted into the computer manually by the range handcrank and dial matching. Because of this, radar range is used if it is available. The range operator, either radar or rangefinder, normally spots in range.

The control officer, pointer, and trainer have firing keys. The pointer's and trainer's firing keys are located on their right handwheels. The control officer's key is a portable firing key. If the director is in control of firing, the battery can be fired from any one of these stations. The circuits to the firing keys are cut on or off at the FC switchboard AA fire is normally controlled by the pointer's firing key, and is backed up by the trainer's key. The control officer gives the order to commence fire. The control officer has a cease fire contact maker.

As previously pointed out, the radar antenna and optics are stabilized in crosslevel (Zd). A self-synchronize Zd power drive is incorporated

in the director. The crosslevel system operates in automatic only. In the event of a casualty, the only alternative is to reset the system to zero by means of a reset handwheel. Indexes on the movable rangefinder beam and its stationary support are aligned at zero. The power drive is activated by a pushbutton in the rear of the director. The starting circuit is interlocked by a switch at the reset handwheel. There is no indicator in the director to show the value of the Zd signal from the stable element. Therefore, before starting the power drive, be sure the stable element's operation is normal. The rangefinder's and antenna's Zd working arc should be free of all obstructions.

Stabilization in the LOS (level), is part of ΔE_b , ($E_b = E + L$). This can be obtained if the director pointer is in automatic, the computer energized, and the stable element operating in full automatic.

Target Designation

The only major problem remaining for the director is the initial acquisition of the target. In the designation mode of operation, train and elevation are in automatic control. If the director assignment console operator in the WDS, or a channel operator in the TDS, designates to the Mk 37, a buzzer sounds in the director. The control officer depresses an "accept designation" pushbutton and the director slews to the designated position in range, bearing, and elevation. If all equipment is aligned and elevation is reliable, the control officer, pointer, trainer, and radar operator should see the target on the radar scopes. If they cannot see the target, a systematic search around the designated position is initiated by the pointer and trainer. When the target is located, the pointer, trainer, and radar operator make refinements in director position, kick their foot switches, and the director locks on in full radar track.

The director's acquisition efforts can be viewed on the designating console. Let's assume that a WDS is installed and that the Mk 37 is director number 2 on our ship. The DAC operator watches the position of the number 2 on his scope as compared with the position of the target data source. The number 2 on the DAC is a "repeat back" signal from the director which indicates the director's bearing and range. When director 2 accepts designation from channel C, for example, the number 2 on the DAC should

slew with the director and eventually be superimposed on the letter C. If searching is required by the director at this point, the DAC operator can frequently coach the director on target by relaying relative position data over his sound-powered telephone. When the director locks onto the target, the control officer throws a "track" switch and a track light is illuminated on the DAC. When the director track switch is activated, the number 2 is illuminated on all target selection and tracking consoles.

In our example we used an installation with a WDS; however, a TDS and Mk 37 director combination function more or less the same. In installations without a three-coordinate search radar, the elevation designation signal is a fixed low value. The Mk 1A does not initiate a search program. The director pointer and trainer generate the search pattern. To assist them, two target acquisition units (TACUs) are installed in the director. The designated train and elevation signals may be altered by operation of handcranks on the TACUs. One turn of the handcrank on the trainer's TACU moves the director 2 degrees in train. A turn of the handcrank on the pointer's TACU moves the director 5 degrees in elevation. Depressing a pushbutton located on each unit removes the search signal and allows the director to return to the designated position. An indicator lamp is illuminated to indicate that the director is in designation mode of operation. The designation mode is initiated by the control officer pushing the accept designation button, and is terminated when:

1. The FC radar shifts to automatic tracking, (locked on).
2. The trainer and pointer shift to local control.
3. The trainer upon orders from the control officer pushes the target designation off button. (This switch activates circuits which causes the director to reject designation signals.)

The search patterns to be followed are given in the ship's gunnery doctrine. These patterns are somewhat similar to those automatically generated in missile computers in that the patterns vary with target range and altitude.

COMPUTER MK 1A

The computer includes most of the controlling, computing, and transmitting fire control mechanisms for the battery. Supplied with the proper hand and automatic inputs, the computer

will compute, indicate, and transmit automatically to the gun mounts and the director the necessary information to point the guns and to keep the director continuously on target. Figure 4-14 shows the computer and most of its operating controls. All Mk 1A computers are basically the same in appearance, function, and operation. The various mods of the computer differ mainly with respect to the self-contained ballistic data which adapt them to particular guns.

General Description

By this time you should know what information the computer requires for the solution of the fire control problem. The table and illustration in figure 4-15 show how the various inputs are normally introduced to the computer, and their source.

The computer is built in four sections:

1. The control unit.
2. The indicator unit on which is mounted the star-shell computer.
3. The computer unit.
4. The corrector unit.

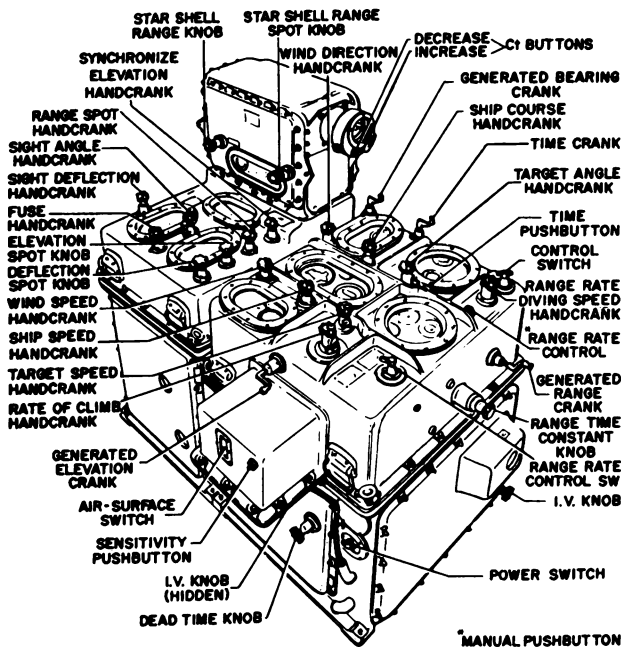
The control section contains the mechanisms for computing rates (range, bearing, and elevation), and carries most of the knobs, cranks, and dials. The indicator section shows the end

result of ballistic calculations—sight angle, sight deflection, fuze order, and advance range. The computer section contains the mechanisms that generate changes in the present position quantities (range, bearing, and elevation), and the mechanisms that make the ballistic calculations. The corrector section computes, indicates, and transmits gun train order, gun elevation order, fuze order and parallax. The problems solved by the computer, and most of the basic mechanisms used in the solution, are described in the FT3 and FT2 courses.

Operation

Computer operation is fully automatic except in the tracking section. Here we are assuming that the computer is casualty free and working with guns whose ballistics are the same as the computer's designed ballistics. The computer has three types of tracking control: normal, test, and local. NORMAL control is the automatic mode of operation, and is used in conjunction with the Mk 37 director. We are not considering interconnections between fire control systems. It is possible for the computer to obtain target position data from the Mk 56 director, for example. In normal control the rate control group computes corrections for the values of target speeds (horizontal and vertical), and target angle. It does not function in test or local operation. The TEST position of the control selector adapts the computer for testing, and is used in surface fire and shore bombardment when target bearing is received from the director. The LOCAL position is used when target position is not measured by the director. Present position quantities are hand inputs. This type of control can be used only against surface targets.

NORMAL CONTROL.—In normal control the computer's hand inputs are preset and all other quantities are automatically driven to their correct position by servosystems. The range and elevation inputs are possible exceptions which we will consider later. The time motor is started when the radar locks on target or the director trainer's rate control key is closed. Rate controlling in full radar control is done automatically by the director staying on target. When the director is in partial radar or optical control, the trainer's and pointer's rate keys must be closed to rate control. The sensitivity of the rate control system is normally sufficient to provide smooth, accurate tracking. If the target



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Figure 4-14.—Computer Mk 1A—operating controls.

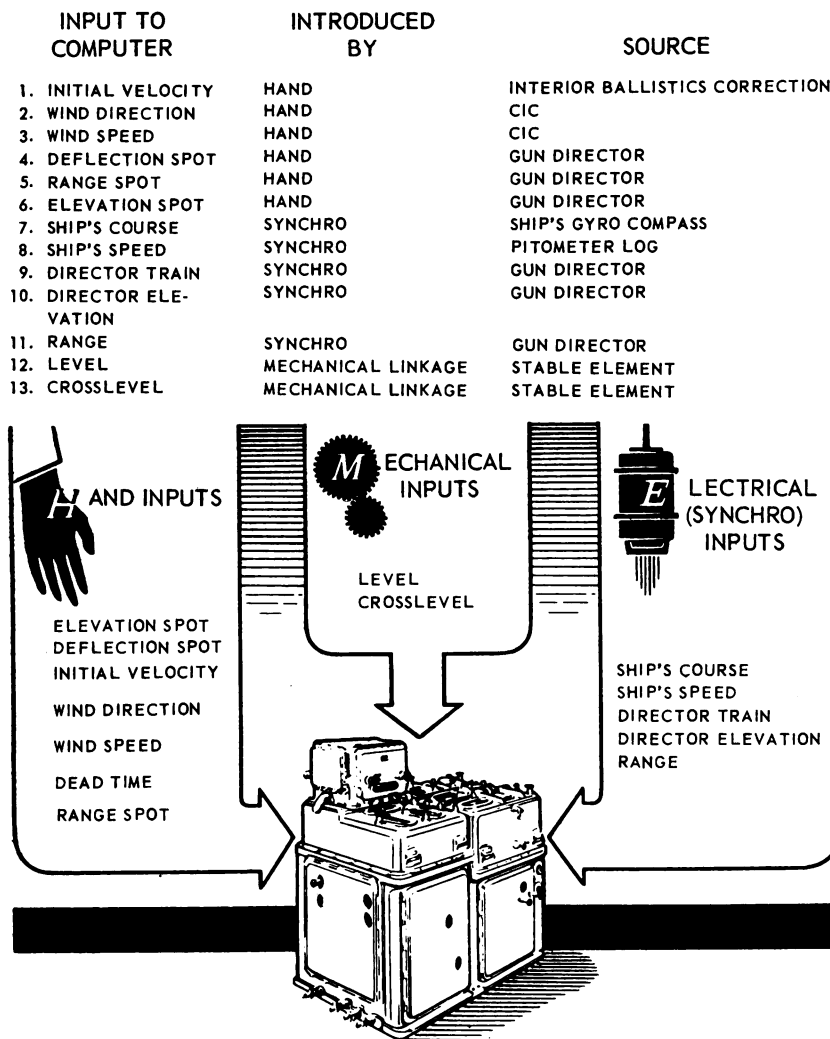


Figure 4-15.—Computer inputs.

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makes a radical maneuver, the computer operators can increase the sensitivity of the system. Range has a sensitivity control knob graduated in seconds. The setting indicates the time required for range rate error to be reduced to approximately 37 percent. Bearing and elevation sensitivity are controlled by a pushbutton which works in conjunction with an air-surface switch. The sensitivity of these networks is varied a definite amount by varying the range input to their rate control systems. This is done for a fixed interval of time by depressing the pushbutton. The controls on the computer are shown in figure 4-14. In full automatic, the

computer operators simply monitor the progress of the solution. There are exceptions to this, however.

It was indicated previously that range from the rangefinder is intermittent. The computer has a range rate control switch with automatic-manual positions. The automatic position is used when observed range is constantly available from the radar. Present range is then driven into the computer by the range servosystem. The manual position is used when the range source is intermittent. The range servo is de-energized, and range is inserted into the problem by dial-matching with the generated range

crank. Range-rate controlling with a manual range-rate control pushbutton is substituted for the automatic process. It was mentioned that the computer was dual purpose. In surface fire, elevation in the tracking and prediction mechanisms is held on zero. Elevation has three types of operation controlled by the synchronized elevation knob of the computer. The knob has three positions.

1. The IN position is used for AA fire. Present elevation is the same throughout the computer. Director elevation and level enter the tracking and prediction sections of the computer.

2. The CENTER position of the knob is used for surface fire when the director is in control of elevation. The elevation line in the computer is broken. Elevation in the tracking and prediction sections is placed and held on zero. Director elevation and level are used to correct gun elevation order in the corrector section.

3. The OUT position of the knob is used for surface fire when the stable element is in control of elevation. The knob actuates a switch which deenergizes the director elevation servosystem. Thus elevation is not received. Elevation in the tracking and prediction sections is placed on zero and held. Firing elevation is based on the horizontal plane measured by the stable element. Dip range is inserted by the synchronized elevation knob as a correction to elevation to compensate for the fact that gun elevation contains a parallax correction due to director height.

There is one other exception—the spot knobs. These knobs are normally kept in the IN or manual position. AA spotting has been eliminated in this system, and surface fire spotting is normally slow. The manual position of the

knobs eliminates the possibility of an erroneous spot entering the computer's solution inadvertently from the director.

LOCAL CONTROL.—Local control of the computer is used for surface fire when the director cannot measure target position. Target position information is obtained from a source outside the FCS. This occurs mainly during shore bombardment. The computer bearing operator can insert target bearing into the computer by using the generated bearing handcrank. The range rate control switch is in the manual position. Range is inserted by the generated range handcrank. Elevation is the same as in surface fire, with the synchronized elevation handcrank in the out position. The rate control mechanisms do not function in local. The target's rate of climb is on zero, and its handcrank is in manual. Target angle and horizontal speed handcranks are in manual. These two handcranks are used to set in target course and speed which compensate for ship's drift. The spotting procedure in local is explained in chapter 7 of this course.

STAR-SHELL COMPUTER

The star-shell computer, which is mounted on top of the Mk 1A computer indicator section, is designed to control the fire of the guns when firing star shells. The star-shell computer determines star-shell gun train, elevation, and fuze orders, which will cause the star shell to burst about 1500 feet above and 100 yards beyond the target. As shown in figure 4-16 the illumination silhouettes the target. The assistant control officer in the Mk 37 director controls star shell fire.

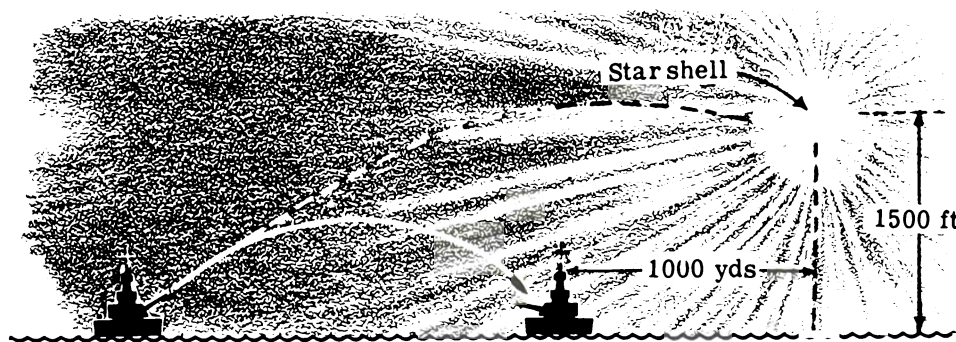
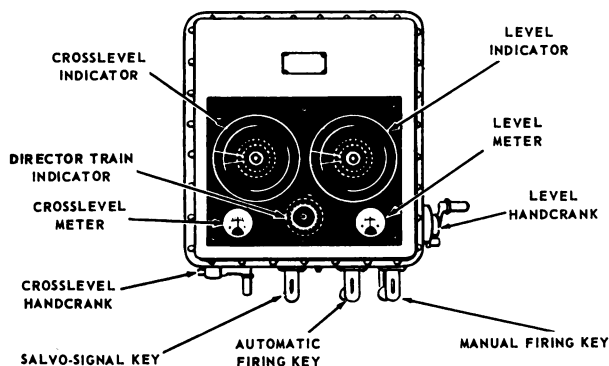


Figure 4-16.—Star shell shoot.

The star-shell computer receives gun train and elevation orders and target range mechanically from the Mk 1A computer. Consequently, illumination fire must be against the same target Mk 1A computer is tracking. The star-shell computer receives illumination spots from the director. These spots affect only the guns switched at the fire control switchboard to receive gun orders from the star-shell computer. Spots applied to the Mk 1A computer to correct the fall of shot of the destructive fire will offset the illumination fire. Thus, spots for destructive fire are reserved and applied to the star-shell computer in this manner.

STABLE ELEMENT

The stable element is located in the plotting room adjacent to the computer, to which it is mechanically connected by shafts. The primary job of the stable element is to maintain the true vertical, and continuously measure level and crosslevel. These quantities are transmitted to the computer and director as shown in figure 4-9. The outputs of the stable element are used to stabilize the director's optics and radar antenna, and in the computer to furnish a horizontal plane in which to solve the fire control problem. The level and crosslevel followup systems keep the sensitive element in the vertical automatically. Handcranks and meters are provided for manually positioning the sensitive element in case of failure in the automatic system (fig. 4-17).



92.20

Figure 4-17.—Top view of stable element.

Another function of the stable element is that of a remote firing station. Its use as such depends on the method of aiming used—"continuous aiming" or "selected level or crosslevel aiming." In continuous aiming, gun train and elevation orders are continuously corrected for deck inclination. Thus the guns always maintain their position in space and may be fired at any time, regardless of the roll and pitch of the ship. Selected level or crosslevel aiming is used when sea conditions make it difficult to keep on target. Since both selected level and selected crosslevel are similar, we will explain only selected level. The guns are not continuously stabilized in level; they move with the ship and can be fired only at the moment the aim is correct. The stable element is provided with a pair of firing contacts in series with the automatic firing key. One of the contacts is fixed in space by the stable element's gyro, while the other contact moves with the ship (fig. 4-18). In the figure, E_g is gun elevation above the horizontal plane, and the firing circuit is complete except for the contacts in the stable element. The contact which moves with the ship can be manually positioned by the level handcrank to a selected value. The selected value of level is an input to the computer, where it goes into gun elevation order.

There are three hand-operated keys on the front of the stable element (fig. 4-16). The manual firing key is used for continuous fire. It is in no way connected with the internal mechanisms of the stable element. The automatic firing key operates in conjunction with the contacts during selected level or crosslevel firing. The third key is the salvo signal key.

GENERAL DESCRIPTION OF GFCS MK 56

Gun Fire Control System Mk 56, illustrated in figure 4-19 is an intermediate-range anti-aircraft fire-control system. Designed for use against high-speed subsonic aircraft targets, it provides gun train, gun elevation, and fuze orders for 3-, 5-, and 6-inch guns. It also may be used against surface targets.

Where a ship has two batteries (of different calibers) capable of AA fire, the system can produce different gun orders for both batteries simultaneously, thus permitting both to fire on the same target. This variation is known as a dual-ballistic system.

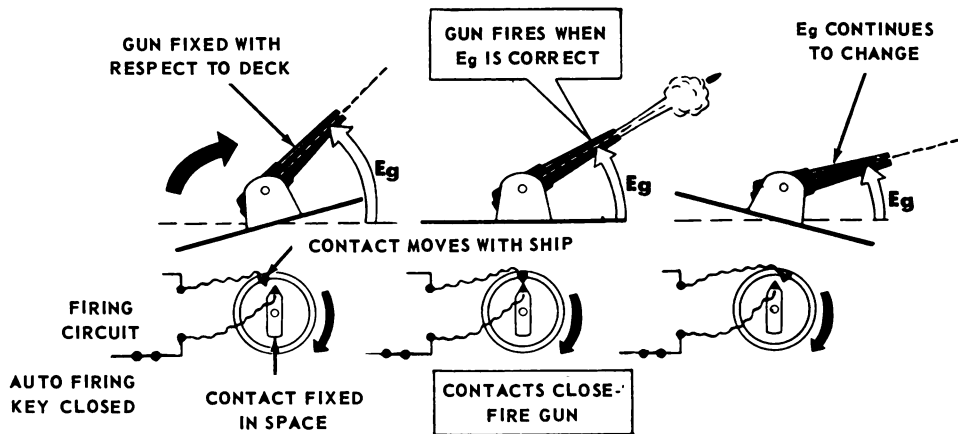


Figure 4-18.—Level's firing contacts during selected level aiming.

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The system incorporates:

1. Automatic radar tracking in bearing, elevation, and range, as accurate as the best optical tracking.

2. Remote control of the entire system from the control room below decks, which provides for rapid radar acquisition of obscured targets and for blind firing. Solution time of this system is relatively short (2 seconds).

The system consists essentially of a two-axis, power-driven, direct-line-of-sight director located above decks, and various computing units located in a control room below decks. Complete radar equipment is included as an integral part of the system. The radar antenna is mounted on the director, and all radar indicators are in the control room.

The system is operated by a crew of four men, including the control officer. The latter and the pointer are stationed in the director for optical acquisition and the tracking of visible targets, and the two other men are at a console in the control room. On the console are all radar indicators and operational controls for handling range and positioning the director. Acquisition of obscured targets is accomplished from the console.

Director line of sight (including radar antenna) is stabilized by a gyro unit in the director. Computation of lead angles is based on director angular rates of motion in stabilized coordinates.

The discussion to follow presents first a general treatment of the fire-control problem as solved by the system, then a detailed description of system components and operational controls.

TARGET POSITIONING BY THE MK 56 SYSTEM

Figure 4-20 shows some of the space relations used in the Mk 56 system. The angular velocity of the LOS can be resolved into angular rates in two planes, elevation and traverse, dE and dB s. In the GFCS Mk 56, these rates are measured by the rate gyro, which is stabilized and hence measures the rates in the true elevation and the true traverse plane.

The solution, however, requires the use of linear rates of target motion, in a plane perpendicular to the line of sight at target's position. This plane is called the cross-traverse plane, and contains RdE and RdB s. The target is not moving entirely in the cross-traverse plane, the range changes at the rate dR , measured along the line of sight. RdE , RdB s, and dR , then, are the three basic linear rates of target motion.

The first step in the solution of the problem by the Mk 56 is the determination of target position. Target bearing and elevation are measured by the director. As the target is tracked, director train, $B'r'$ and director elevation $E'b$ are measured and transmitted continuously to the computer. Target range (R) is measured by gating the target pip on the radar indicator. The range signal is transmitted automatically from the radar equipment to the computer.

Tracking the target is accomplished either optically or by radar. For optical tracking, a hand-grip type of tracking control unit and a

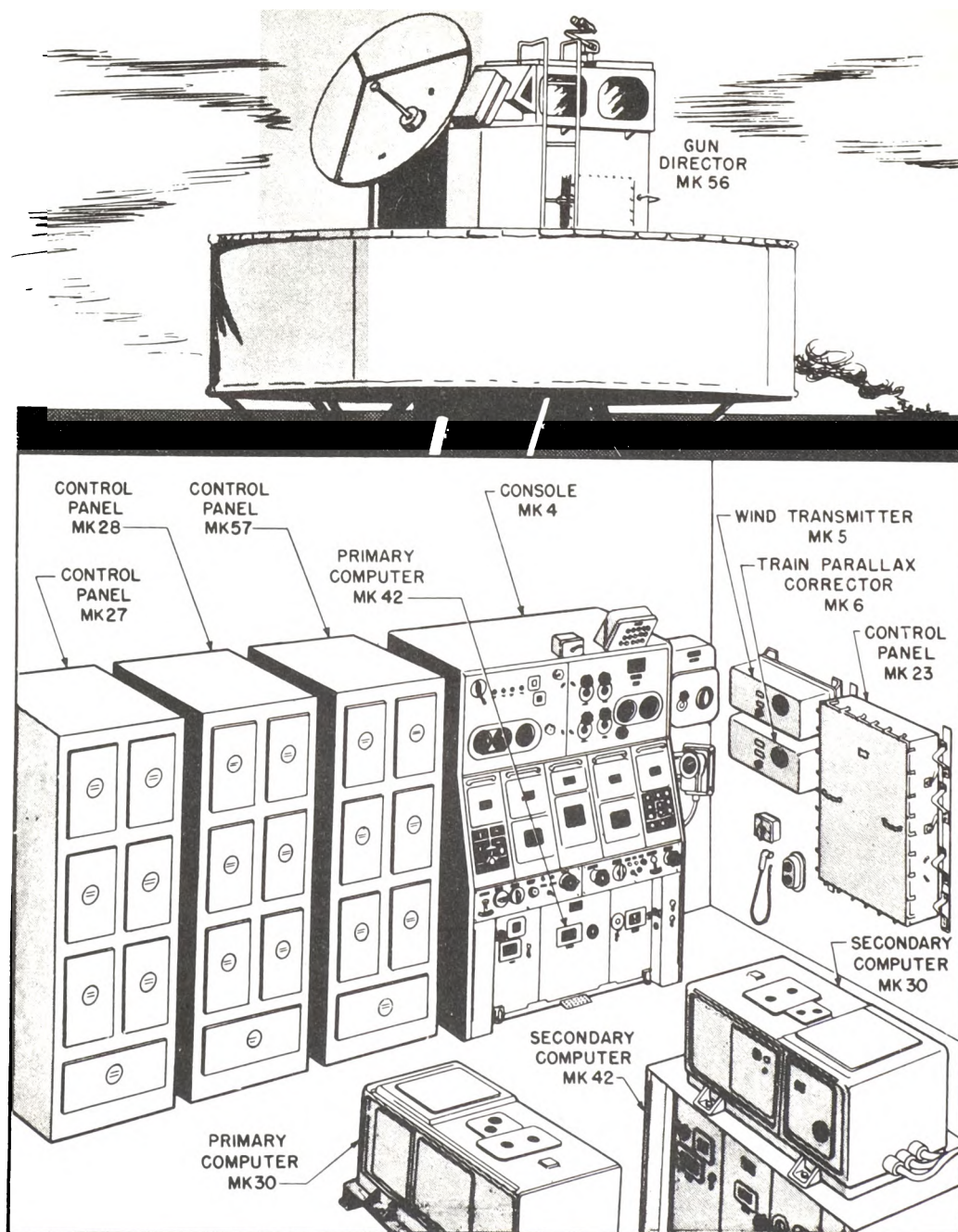
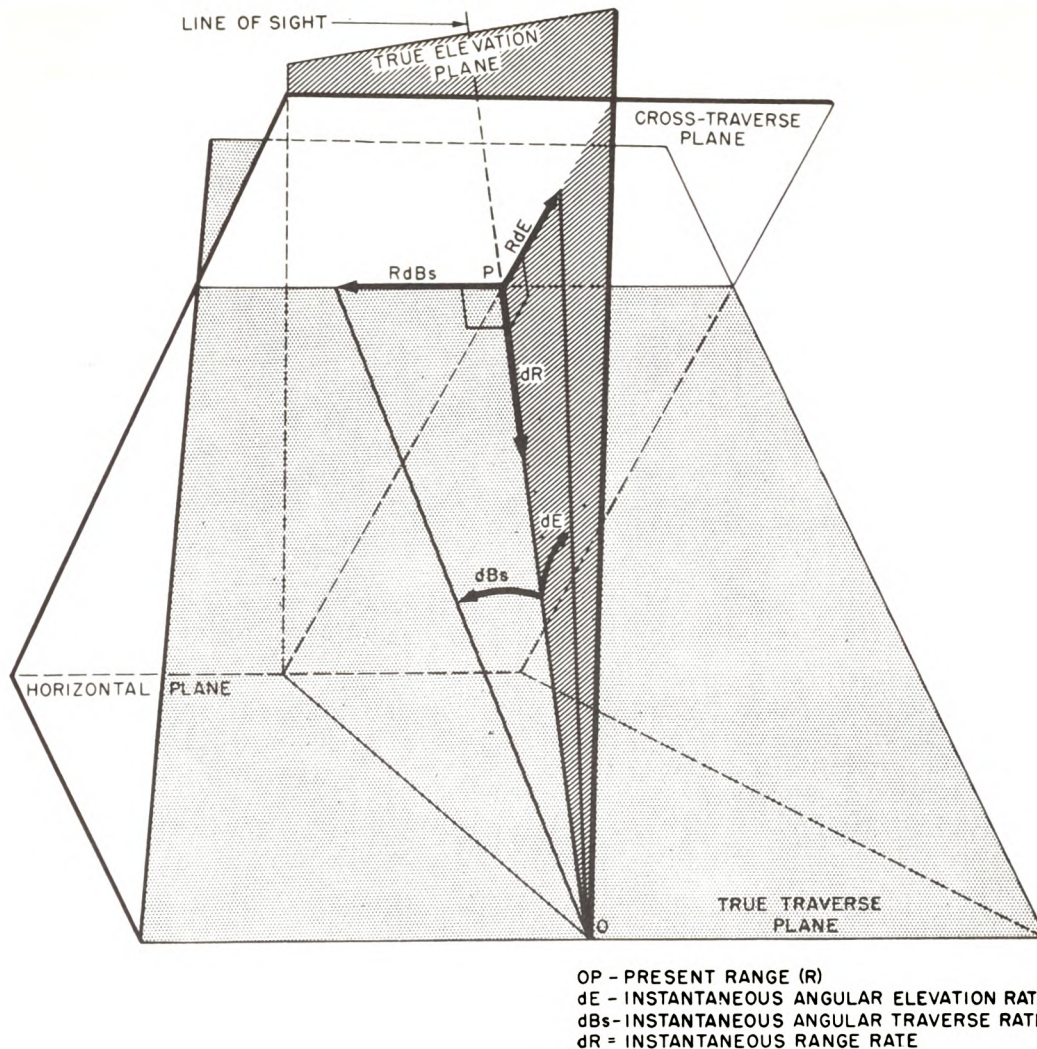


Figure 4 19.—Components of gun fire control system Mk 56.

92.22

telescope are provided on the director. Rotation of the hand grips generates electrical signals that control the director power drives in elevation and train.

In automatic radar tracking, the tracking signals originate in the automatic tracking circuits of the radar equipment. These error signals vary with deviation of the target from the



92.23

Figure 4-20.—Linear rates of target motion.

center of the radar beam when in conical scan. Automatic tracking is accurate within one-half mil.

The director line of sight is stabilized by a gyro unit, located in a compartment at the rear of the director. The unit, shown schematically in figure 4-21 consists of a vertical gyro and a rate gyro. The gyroscope unit is mounted on pivots in the gyro compartment. The elevation linkage attached to the antenna elevating gear is used to tilt the gyro main (elevation) gimbal so as to maintain the gyro gimbal axes parallel to the line of sight.

The primary purpose of the vertical gyro is to establish a stable reference plane called the true traverse plane, as shown in figure 4-20.

The vertical gyro, as shown in figure 4-22, also measures E , true elevation of the director line of sight above the horizontal; and Zs , cross-traverse angle. Like crosslevel, cross traverse is motion about the line of sight due to movement of the deck. However, cross traverse is measured in the cross-traverse plane and therefore differs from crosslevel. The values of E and Zs are picked off by elevation and cross-traverse control transformers and are transmitted to the computer, where they are applied in calculating ballistic corrections and gun orders. Zs also goes to the cross-traverse drive gear of the rate gyro.

The rate gyro, shown in figure 4-23 controls the drive motors which position the director in

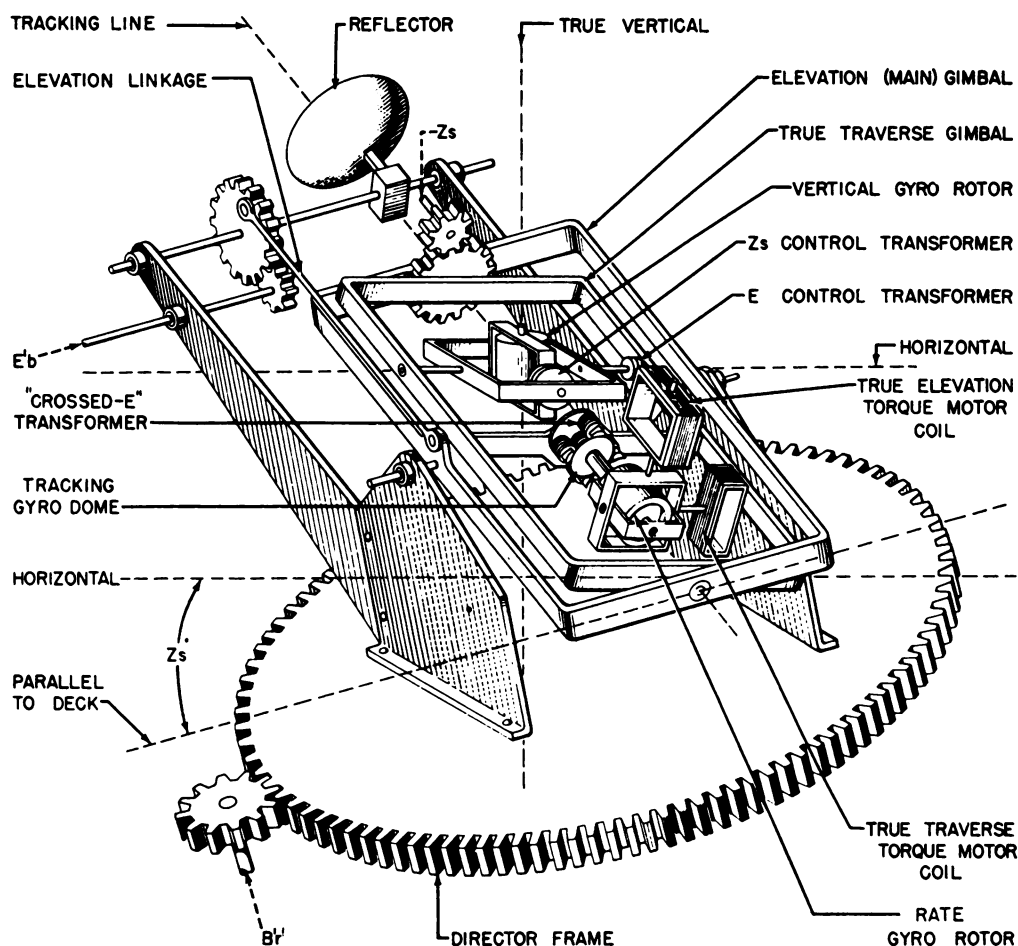


Figure 4-21. —Gyro system schematic.

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train and elevation. The gyro does this by measuring the angular rates of target motion in the form of electrical tracking signals and combining these signals with the stabilizing signals E and Zs from the vertical gyro. The algebraic sum of these signals is obtained in a set of pick-off coils called a crossed-E transformer and shown in figure 4-23. The crossed-E transformer is composed of five coils arranged to form a cross with axes at right angles. The center coil is energized by 100 volts, alternating current. This voltage induces voltages in the other coils which are connected in phase opposition. Supported by the vertical frame, two coils are kept oriented in the vertical plane through the tracking line, as shown in figure 4-21 and are connected in phase opposition. The other two coils are oriented in the true traverse plane. Carried on the rate gyro shaft is the reluctance dome.

When the rate gyro is positioned with its center over the center coil of the crossed-E transformer, the air space between the dome and the transformer coils is the same, and the voltages induced in the coils on opposite sides of the transformer are the same, but opposite in phase. Consequently, the output is zero. When the dome moves off center, the voltages in opposite coils become unequal and error signals in elevation and traverse are generated.

The error signals in elevation and traverse form part of the input to the director drive motors. In this manner, the director is driven to stay on the target, even though the ship is rolling and pitching.

MEASURING RATES OF TARGET MOTION

If the director remains on target continuously, the angular rates of director motion are

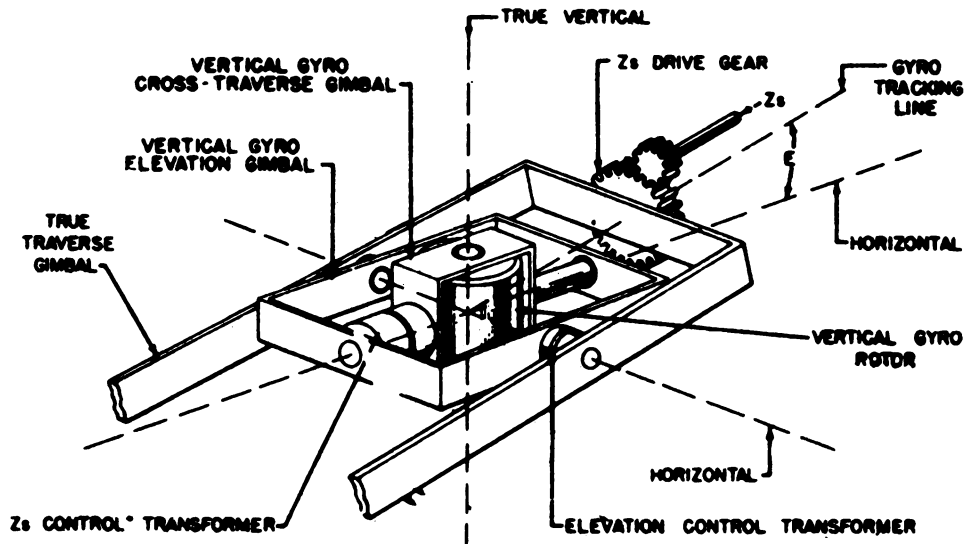


Figure 4-22. —Vertical gyro.

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the same as the angular rates of relative target motion. Therefore, the train and elevation tracking signals are transmitted to the computer as rates of target motion, dE in elevation and dB in traverse.

In obtaining these rates of target motion, the property of gyroscopic stability is used. As the

director tracks the target, the rate gyro tends to lag behind, causing the radar antenna and the optical telescopes to lag. The need for correction becomes obvious to an optical tracker, who gets back on the target by handwheel motion, thus correcting the error. With automatic radar tracking, error signals are

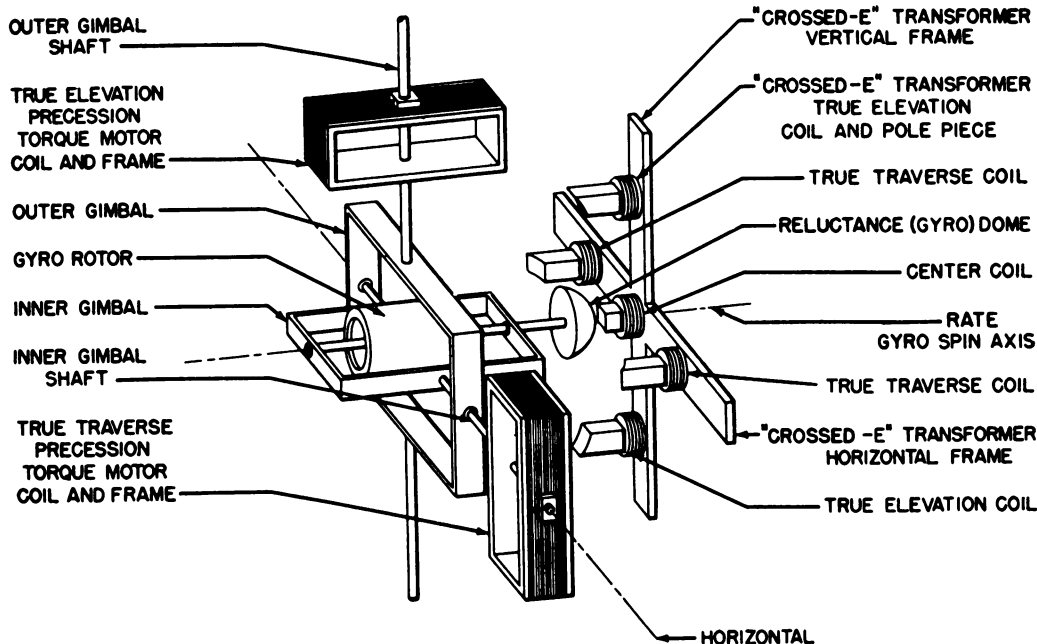


Figure 4-23. —Rate gyro and crossed-E transformer.

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introduced electronically. In either type of tracking, the error signals generated go to the elevation and traverse torque motors shown in figure 4-22. The gyro is precessed to follow the target, which causes the reluctance dome carried by the gyro to move off center. Voltages are induced in the coils of the crossed-E transformer, and these voltages are used to drive the director in train and elevation until the director line of sight is back on the target.

The crossed-E transformer receives error signals due to tracking rates and stabilizing signals due to deck inclination. The two are continuously combined, and the director is driven to correct for both effects.

Also required in computing lead angles is range rate, dR , which is obtained from a tachometer attached to the shaft of the range servo motor. The tachometer is a small generator whose output voltage varies with speed of rotation. The output voltage is therefore a measure of the rate at which the range motor is rotating, in other words the rate of change of present range.

From the three rates of target motion, dE , dBs , and dR , the computer calculates lead angles in true traverse and true elevation to account for movement of the target during time of flight.

BALLISTIC CORRECTIONS

The computer consists of the following units: ballistic computer, wind transmitter, parallax corrector, and gun order converter, together with associated amplifiers. Computations are performed by a chain of electrical and mechanical networks distributed among these units.

Based on the inputs of present target position and rates of target motion, the computer calculates superelevation and drift. To correct for the effects of wind, the computer receives electrical values of own-ship course speed, and manually introduced values of true wind speed and true wind direction, and own ship's speed. Corrections are made for the effects of apparent wind upon projectile travel in elevation, traverse, and range.

The ballistic corrections in the Mk 56 system are computed in terms of rates. In accomplishing this the angular rates dE and dBs received from the director are first multiplied by R to give linear rates RdE and $RdBs$. Then cor-

rections to the linear rates, RdE , $RdBs$, and dR are worked out for superelevation, wind, etc. For example, $RdBsf$ is the correction to $RdBs$ for drift, $RdBsw$ for wind. The final corrected rates, shown in figure 4-24 become $RdBstfw$, $RdEtfpw$, and $dRtfw$. The t indicates relative target motion and the p a correction for vertical parallax.

Unlike other systems, the Mk 56 does not multiply the applicable linear rates by time of flight to obtain lead angles V and D . Instead, the rates are divided by average shell velocity

U , where $U = \frac{R2}{Tf}$. Basing the solution on U , the

average velocity, gives more accurate predictions. The most accurate solution is obtained at a medium range, with accuracy decreasing to give maximum error at either a short range or maximum range. However, the maximum errors are so small they do not effect the accuracy of gunfire appreciably. With a chronograph operating in conjunction with the radar, very accurate values of U are obtained.

When U is not measured by chronograph, the computer must receive a manual input of initial velocity to correct for variations in projectile velocity caused by gun erosion, powder temperature, and atmospheric density. When the chronograph is used, the input is actual average velocity of the projectile in flight.

A manual input of dead time must also be introduced into the computer to compensate for the effect of gun-crew loading time upon fuze time order.

The lead angles V and D , shown in figure 4-24, are in the true elevation and true traverse planes. Since present target position is measured in deck coordinates, the lead angles must be converted into their equivalent angles in deck coordinates. This conversion is performed in the Mk 30 computer by a graphic device called the axis converter. The converter is a small dummy-gun arrangement which reproduces the actual conditions of the problem. The stabilized lead angles are set into the converter, and the correct values of lead angles in deck coordinates are continuously picked off and used in making up gun orders.

Parallax correction is accomplished in three parts: (1) an elevation correction to account for the vertical displacement of the gun mount from the director, (2) a correction to director train to correct for the fore-and-aft displacement of

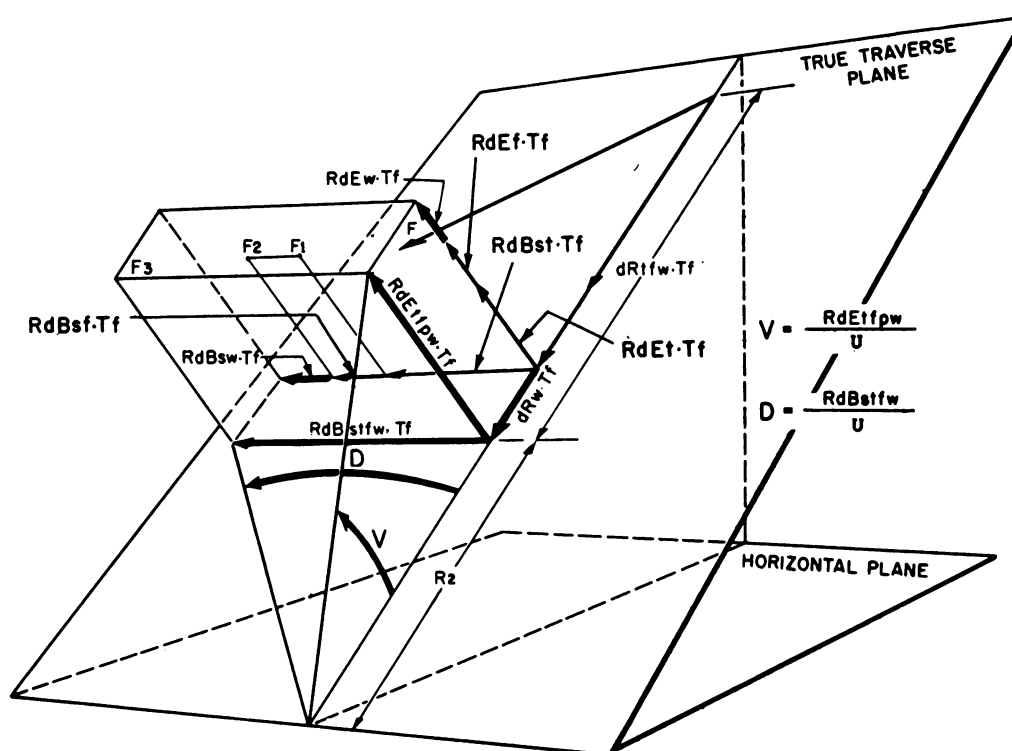


Figure 4-24.—Target-motion lead angles.

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the director from the ship's reference point, (3) unit parallax correction (100-yard base length), which is transmitted to the gun mount, where a correction is made to gun order for displacement of gun mount from reference point.

COMPOSITION OF GUN ORDERS

With the lead angles V and D in true coordinates converted to the deck-plane coordinates as $V'd$ and $D'd$, they can be added to $E'b$ and $B'r'$. Gun elevation order $E'g = E'b + V'd$ and gun train order, $B'gr = B'r' + D'd$. These values are transmitted to the guns, where a final correction for horizontal gun parallax is introduced into gun train order.

The fuze setting order (F) for mechanical time fuzes is computed in the Mk 42 computer.

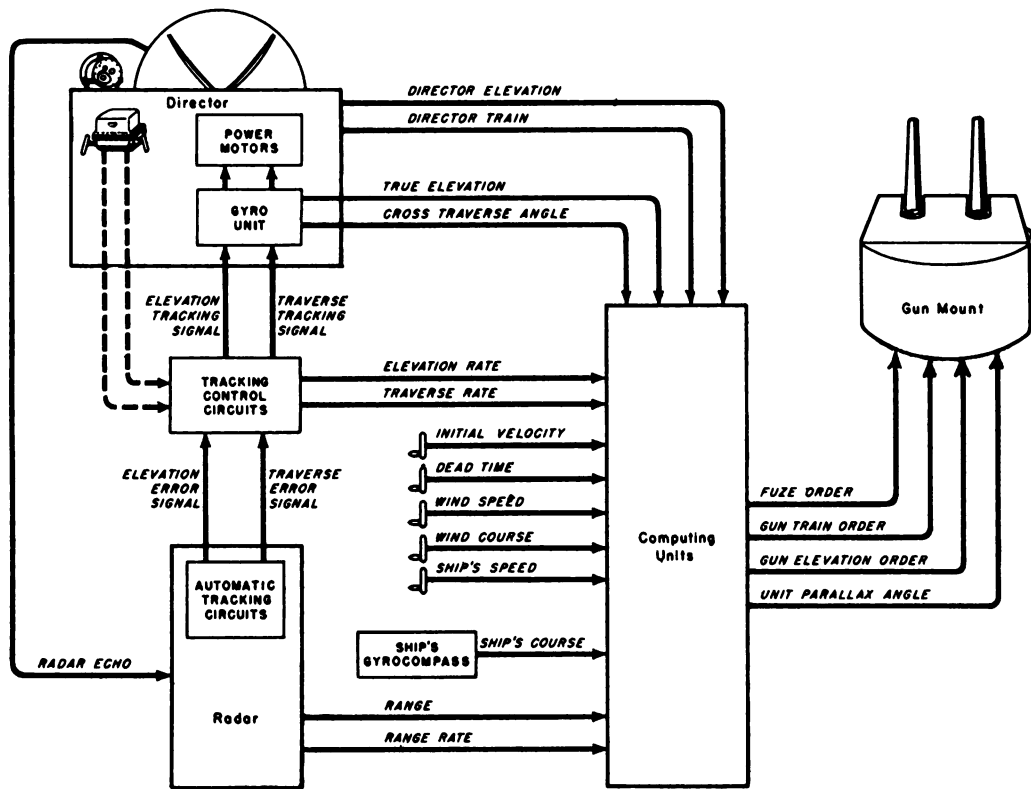
SUMMARY OF SYSTEM OPERATION

Figure 4-25 shows the flow of basic quantities in the system when using automatic radar tracking, which is the usual method of operation. The radar equipment in the radar room receives

target echoes from the antenna and transmits traverse and elevation error signals to the gyro unit as tracking signals and to the computer as rates of target motion. By resetting the control switches, signals from the optical tracking control unit in the director may be selected in place of radar error signals. The radar equipment transmits range and range rate to the computer during both radar and optical tracking.

In the gyro unit, tracking signals are added to stabilizing signals. The resultant signals control the director power drives. As the director tracks the target, director position is measured by synchros, and director train and elevation are transmitted to the computer. The gyro unit also transmits values of true director elevation and cross-traverse angle to the computer.

Own-ship course and own speed are introduced to the computer electrically, while true wind speed, true wind direction, initial velocity, and dead time are introduced manually. The computer calculates lead angles and ballistic corrections, and makes up and transmits gun elevation order, gun train order, fuze time order, and unit parallax correction to the guns. Within



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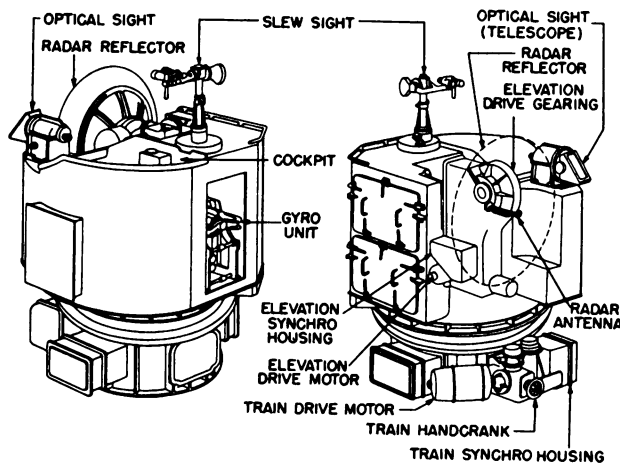
Figure 4-25.—Flow diagram of basic quantities, GFCS Mk 56.

two seconds of the start of steady tracking (either optical or radar), the computer is producing accurate gun orders.

SYSTEM COMPONENTS

1. Gun Director Mk 56 (fig. 4-26) is located above decks, in a position affording maximum visibility. Its primary function is to supply the computer with continuous present target position and rates of target motion. A two-man director-operating crew is stationed in the left section, called the cockpit, with the control officer behind the pointer. In the cockpit are the tracking controls and various dials and switches used to operate the system. The right section consists of four watertight compartments which house the gyro unit and various above-deck units of Radar Equipment Mk 35. Mounted on the director are the slewing sight, telescope, tracking control unit, and radar antenna.

The slewing sight consists of a pedestal with an elevating crossarm on which a binocular is mounted. Rotation of the pedestal about its vertical axis generates an electrical signal that positions the director in train. Rotation of the crossarm about a horizontal axis generates



92.28

Figure 4-26.—Gun director Mk 56.

an electrical signal that positions the director in elevation. Slewing sight operation is controlled by a two-position switch at the pedestal base. With the switch in LOCK, the slewing sight will follow the director; in SLEW, the director will follow the slewing sight.

The pointer's tracking control unit is used for moving the director when tracking visible targets. This unit rotates about a vertical axis. The handgrips rotate about a horizontal shaft. Rotation about either axis generates an electrical signal that controls the director power motors.

The radar antenna assembly consists of a parabolic reflector, a nutating antenna feeder, and a scanning mechanism. The entire assembly, mounted on trunnions and connected to the director elevation gearing, elevates with the line of sight.

The antenna forms a beam of set width. The scanning mechanism nutates the beam in either conical or spiral scan. In conical scan, the beam nutates through a cone of set diameter. In spiral scan, the beam nutates in a spiral pattern, providing a coverage in bearing and elevation.

The director is power driven in train and elevation by d-c drive motors controlled by below-decks amplidyne generators. Movement in train is unlimited, because all electrical connections to the director are through a slip-ring assembly located at the base of the director. Movement of the director in elevation is limited by mechanical stops. Electrical limit switches cut out power to the drive motors before the mechanical limit stops are reached.

A train handwheel and an elevation handknob are provided so that the director may be moved for securing purposes when the power motors are off. There is no provision for manual operation of the director.

For transmitting values of train and elevation, the director is provided with synchro transmitters connected to the train and elevation drive-gear systems.

2. Radar Equipment Mk 35 supplies: (a) the computing units with continuous values of target range and range rate for both optical and radar tracking; and (b) the director with signals for tracking obscured targets. Once on target, the system will track automatically when radar control is being used.

Components of Radar Equipment Mk 35 located above decks are the antenna, transmitter and receiver. The radar indicators, range

controls, adjustment controls, and automatic tracking circuits are located below decks on Console Mk 4.

3. Console Mk 4, figure 4-19, is the below-decks operational center. On it are the knobs, dials, and indicators necessary for below-decks operation of the system. While various phases of the computations are performed in separate computing units, inputs and power to these units are controlled from the console.

The console consists of four main sections: a dial section at the top, the radar section, the operational section, and Computer Mk 42 at the bottom. Bearing Indicator Mk 10 is mounted on the right side of the console.

On the face of the dial sections are knobs and dials for hand inputs to computing units; dials indicating range, elevation, and bearing; tracking-control indicating lamps; and a switch controlling computer operation.

The radar section consists of five panels containing the A/R-indicator, E-indicator, and B-indicator and switches for controlling radar operation.

The operational section contains the hand-knobs, slew levers, and switches for controlling the director in train and elevation, and for controlling range and antenna scan from the console.

4. Computer Mk 42, figure 4-27, is the ballistic computer. Its primary function is to compute projectile time of flight, superelevation, drift, range rate, and fuze order.

Dials indicate I. V. setting, true elevation of the director, range input to the ballistic computer, range rate as computed by the ballistic computer, and fuze order being transmitted to the guns. Knobs are provided for setting these values manually when performing tests; however, for normal operation, the true-elevation, range-rate, and fuze-order knobs are removed from their sockets and stowed as shown in figure 4-27, and the range knob is disengaged. Only the initial velocity (I. V.) knob remains engaged.

The pedal below the center panel of the ballistic computer controls the type of antenna scan.

5. Computer Mk 30 is called the gun-order converter. Its basic function is to convert the rates of target motion in true coordinates into lead angles in deck coordinates, and combine them with director train and elevation to produce gun train and elevation orders.

Four dials indicate director elevation, director train corrected for parallax, gun train

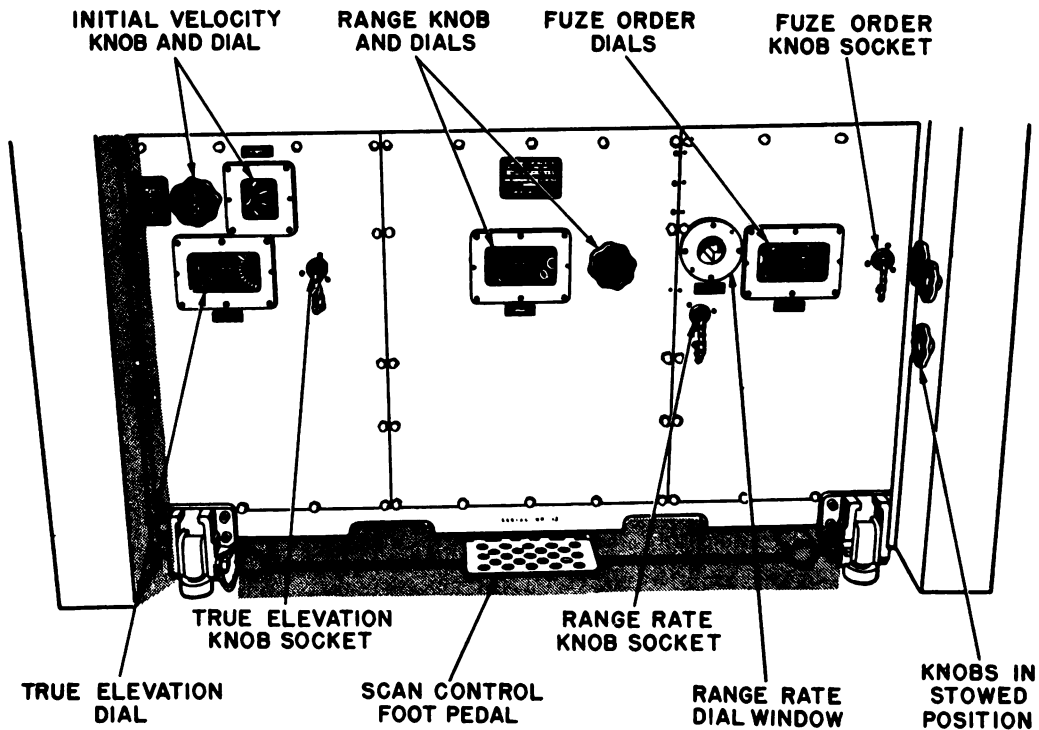


Figure 4-27. —Computer Mk 42.

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order, and gun elevation order. The input value of the cross-traverse angle is visible through a window.

6. Wind transmitter Mk 5 computes corrections to compensate for the effect of wind on projectile flight, and transmits them to the gun-order converter for inclusion in the solution of the problem. Electrical inputs of wind direction, wind speed, and ship speed are received from the console. A dial on the face of the wind transmitter indicates the direction from which apparent wind is blowing.

7. Train parallax corrector Mk 6 computes a correction for the displacement of the gun mount from the director along the ship fore-and-aft axis. It receives values of range, elevation, and director train. The outputs are: (a) director train corrected to the ship reference point which is transmitted to the gun order converter; (b) unit parallax correction, which is transmitted to the gun for correcting the value of gun train order. A dial indicates the unit parallax correction.

8. The chronograph measures the average velocity of the projectile.

9. Bearing indicator Mk 10 indicates director bearing (both relative and true) to the below-decks operating crew.

DUAL-BALLISTICS UNITS

A dual-ballistics system tracks one target but computes two sets of gun orders for guns of different ballistics. For example, in a typical destroyer installation, GFCS Mk 56 computes gun orders for 3"/50 and 5"/38 caliber guns.

The dual-ballistics system requires a second Computer Mk 42 for the secondary ballistics, using the same inputs as the primary ballistics computer, and a Computer Mk 30 which computes gun train order and gun elevation order for the secondary ballistics.

The ballistics selector switch controls power to the secondary ballistics computing units. It has two positions: PRIMARY and BOTH. The secondary units are energized when this switch is in BOTH.

The secondary ballistics fuze control unit controls fuze orders for the secondary ballistics.

CONTROL OFFICER'S STATION

The control officer has available the following operational controls:

1. Telephone-selector switch. This selects the telephone circuit or circuits he wishes to use. To speak directly to the radar operator or gun captain, he turns this switch to LOCAL. To parallel the circuits, he turns it to BOTH. Normally he leaves it on AIR DEFENSE.

2. Slewing sight and slew switch. This is used to slew the director to a visible target. Before the control officer can move the director by means of the slewing sight, he must position the slew switch to SLEW. With the slew switch on LOCK, control of the director reverts to another unit and the slewing sight will follow the director line of sight in train and elevation. The slewing hand grip contains a press-to-talk button equivalent to the mouthpiece button of the control officer's sound-powered telephone.

3. Radar-optical switch. This switch takes precedence next after the slew switch. When the slew switch is on LOCK, the radar-optical switch can select either the director operator's tracking control unit (switch on OPTICAL) or the radar tracking circuits and remote director controls on the console (switch on RADAR).

4. Cockpit dial unit. This is used in positioning the director on the bearing and elevation of a designated target.

5. Standby range input unit. If the radar fails, the control officer can introduce values of estimated target range in increments of 1,000 yards. Normally, however, radar range is selected.

6. Angle-spot transmitter. This device has two dials, each graduated in mils. The upper is the elevation-spot dial and the lower is the deflection-spot dial.

7. Cease-firing contact maker. This is for communicating CEASE FIRING order to the gun crew.

DIRECTOR OPERATOR'S STATION

1. Telescope Mk 60. The director operator tracks a visible target by keeping the crosshairs of the telescope reticle on the target.

2. The tracking control unit is operated to position the director when tracking a target optically. The slew switch must be in LOCK and the radar-optical switch in OPTICAL.

Since tracking signals are used in the computer as the rates of target motion, smooth

tracking is of primary importance to the computation of accurate gun orders. To facilitate smooth tracking, an aided-tracking key is provided in the left-hand grip. When the key is closed, the tracking signals are fed through an aided-tracking circuit. The circuit is designed so that, for an instant after the tracking signals are changed (as the crosshairs drift off target), the director moves at higher rates than those called for by the new rates. The result is that the line of sight "hops" closer to the target and then settles down to the new rates. The director operator holds the aided-tracking key closed whenever he tracks a target.

A firing key with a safety lock is inset in the right-hand grip of the tracking control unit. To close the firing key, the director operator must first release this safety lock by pressing the lever to the left.

3. Open sight. An aid for getting on target.

4. The "press-to-talk" pedal is equivalent to the mouthpiece button used by the director operator. It permits the director operator to talk on his phone circuit while both hands are occupied with the tracking control unit.

5. The amplidyne power switch controls power to the amplidyne generators which supply the director drive motors. The amplidynes will not start before the gyro READY lamp lights, or the securing locks are off.

6. The cockpit illumination switch controls dial illumination to the cockpit dial unit, standby range input unit, and telescope reticle lamp.

RADAR OPERATOR'S STATION

The radar operator has available the following operational controls (fig. 4-28):

1. Radar indicators. Two oscilloscopes, the A/R-scope and the E-scope, provide the radar operator with his "view" of the target.

The A/R-scope (figs. 4-28 and 4-29) has a double-trace presentation. The lower trace (A-sweep) extends from 0 yards. The range mark is movable and can be set on the target pip. Scribe marks on the scope face indicate the graduations in yards. The upper trace (R-sweep) is the expansion of the A-sweep, 500 yards either side of the range mark. The range step remains fixed near the center of the R-sweep and coincides with the range mark. Echoes from stationary targets and the 1000-yard markers (only one of which is visible at any time) move past the range step as the target pip is moved along the A-sweep.

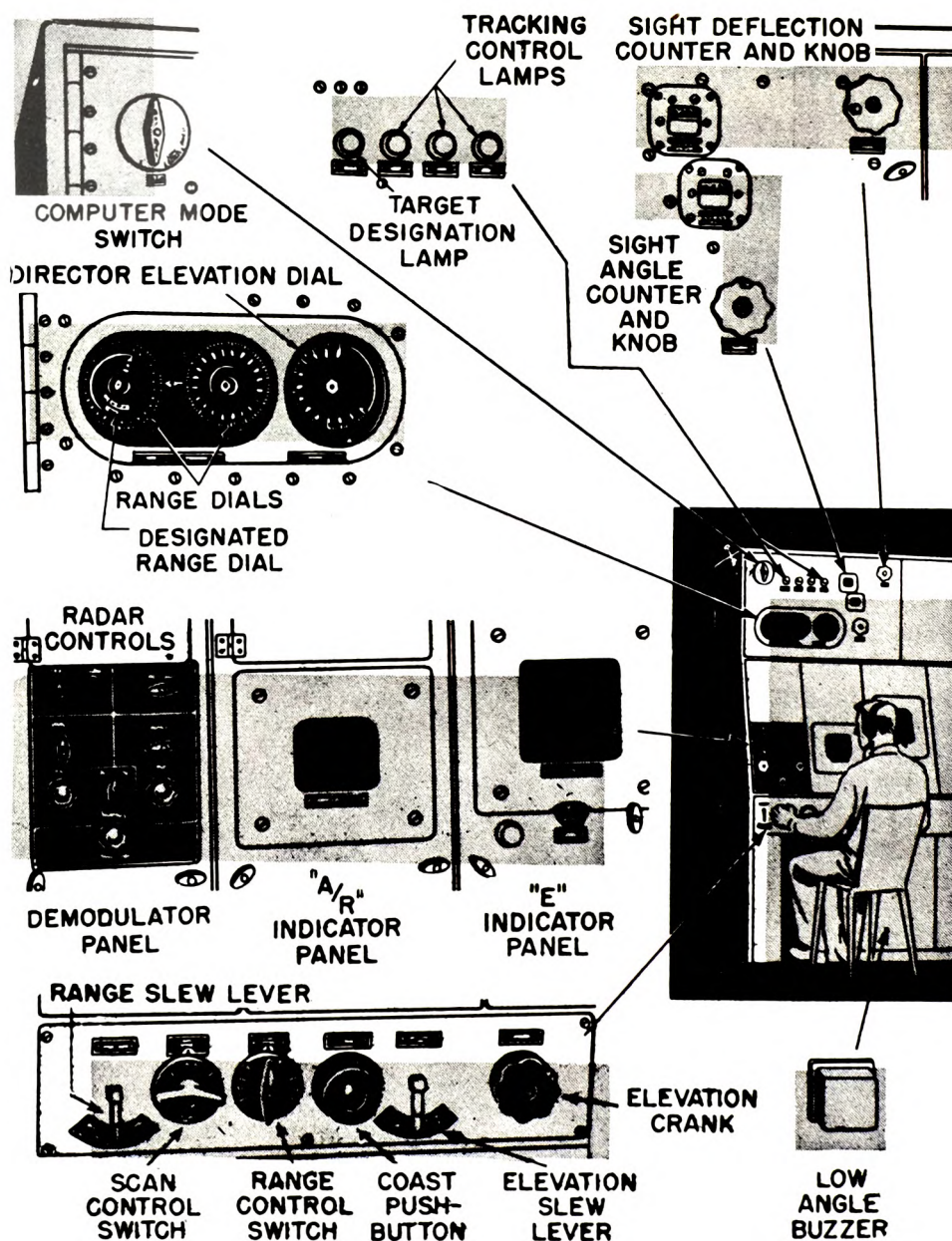


Figure 4-28. —Radar operator's controls.

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The E-scope (fig. 4-30) shows range (horizontally) in yards, and director true elevation (vertically) in degrees. The vertical width of the trace depends on the type of antenna scan. The range mark is a bright vertical line extending from top to bottom of the sweep. Target echoes are vertical lines in elevation. Two curved lines on the scope face furnish an indication of target altitude.

Although normal E-presentation is generally used, an expanded presentation is available by turning the elevation sweep switch to EX-PANDED. Expanded sweep shows the same trace as normal, except that it is expanded in elevation and its center is fixed at the center of the scope. It gives no indication of director elevation.

Also on the E-indicator panel is the console control-indicator lamp, which is lit when the

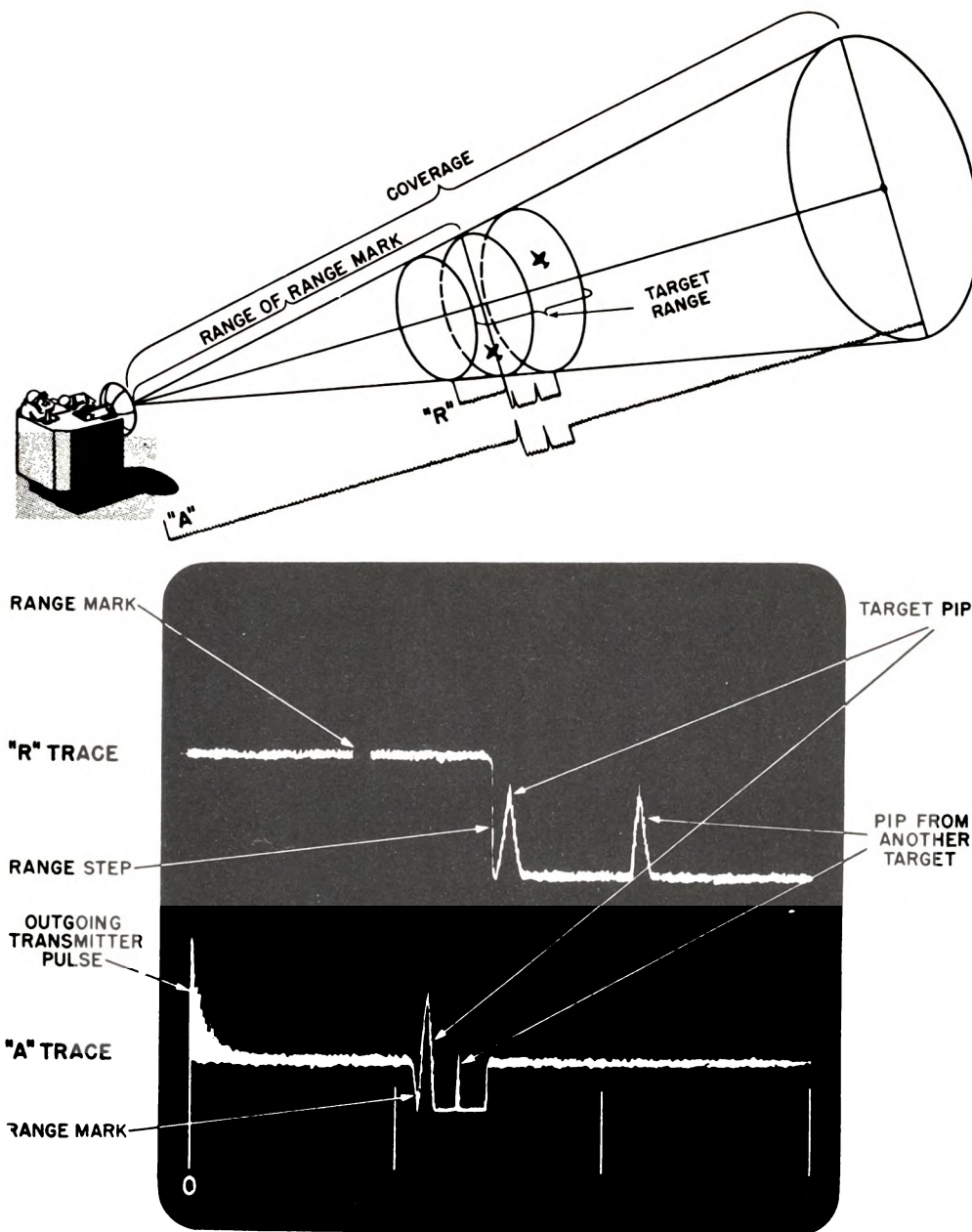


Figure 4-29. —A/R-scope presentation.

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control officer has relinquished control of the director to the below-decks operators (by placing the slew switch on LOCK and the radar optical switch on RADAR).

2. The range slew lever is used for slewing the range mark to the target pip or to a designated target range.

3. The range control switch. This controls the mode of range operation. The range input signal may come from:

- Radar operator's range slew lever.
- Radar tracker's range crank.
- Automatic range-tracking circuit.
- Range memory circuit ("coast" button).

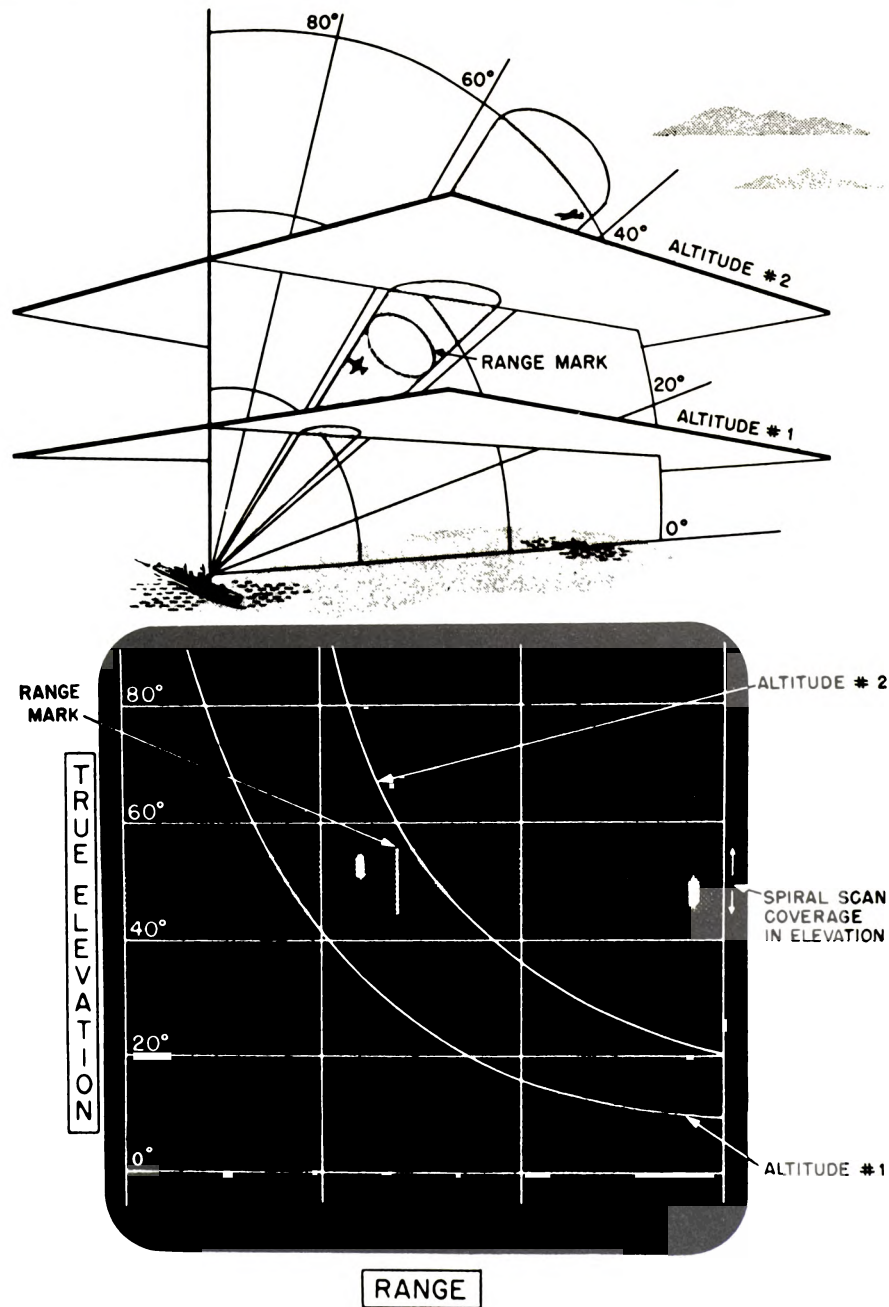


Figure 4-30. — E-scope presentation.

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- e. Control officer's standby range input unit.
- f. Target designation station.

4. The elevation slew lever is used to position the director in elevation when searching for an obscured target.

5. The elevation crank controls director elevation and allows for finer control than the slew lever.

6. The scan control switch, which controls the type of antenna scan, is usually placed on the foot switch so that the scan control pedal can be used to select the type of scan.

7. The coast push button allows the system to "coast" through radar interference such as: (a) obscuring echoes from objects close to the target; or (b) radar "blind spots" caused by own-ship structure. This push button cuts out the automatic tracking circuits and substitutes the memory circuits, which maintain the existing rates of motion in traverse, elevation, and range. The system will coast at these rates for as long as the button is pressed, up to a maximum time of about two minutes. However, the button should be pressed only long enough for the target pip to clear the interference. When the button is released, the automatic tracking circuits will lock back on the target pip if the beam is sufficiently close to the target; if not, the console operators must get back on target manually.

8. The radar controls are the knobs on the demodulator panel which control the operation of the radar equipment.

9. Range and elevation dials. The radar operator approximates director elevation and range from the normal E-scope presentation. For precise indications, he uses a fine and a coarse range dial, and an elevation dial which indicates elevation above the deck.

The range dials indicate the value of range being introduced to the computer (normally this is radar range). The designated range pointer indicates the value received from the target designation station.

10. The computer mode switch controls the mode of computer operation. On NORMAL, it allows the traverse and elevation tracking rates to be introduced to the computer as the rates of target motion.

On LOW-ANGLE TARGET it discards the erratic elevation tracking rates due to water reflection of radar energy when tracking targets below one-degree elevation, and substitutes a fixed zero elevation input to the computer. The traverse tracking rate is retained.

On MANUAL INPUT, which is used for long-range surface fire (in which computer lead angles and ballistic corrections are not accurate), the computer does not calculate lead angles or ballistic corrections. Instead, it used manually introduced values of sight angle and sight deflection as lead angles, combining them with director elevation and director train to produce gun orders.

11. The low-angle buzzer informs the console operators when to change the setting of the computer mode switch. The buzzer is energized:

a. When director elevation drops below one degree, if the computer mode switch is on NORMAL, and

b. When elevation rises above one degree, if the switch is on LOW-ANGLE TARGET. Changing the switch setting silences the buzzer.

12. The target-designation indicating lamp is controlled from the target-designation station. When the lamp is lit, a target is being designated to the system.

13. The tracking-control indicating lamps indicate the settings of the control officer's slew switch and radar-optical switch.

14. The sight-angle and sight-deflection knobs and counters are used during long-range surface firing when the computer is operating in manual input. The sight-deflection counter is calibrated in mils; its zero setting is 500. The sight-angle counter is calibrated in minutes; its zero setting is 2000. For normal operation of the system, both counters are set to their zero settings.

RADAR TRACKER'S STATION

The radar tracker has available the following operational controls (fig. 4-31):

1. The system power controls are the various push buttons and indicating lamps with which the radar tracker controls power to the system. They are located on the console synchronizer panel to the right of the radar indicators.

2. Radar indicators are the radar tracker's "view" of the target, obtained from the E-scope and the B-scope. Since the B-scope covers a range interval of only 2000 yards, the radar tracker, when searching for a target, watches the E-scope to help the radar operator spot the target pip. Otherwise he directs his attention exclusively to the B-scope.

The B-scope presentation (fig. 4-32) shows bearing (horizontally) either side of director train, and range (vertically) 1000 yards either side of the range mark. The trace appears as a vertical band, the center of which is always at the center of the scope. The width of the trace in bearing depends on antenna scan. The range mark appears as a horizontal line at the center of the scope, extending across the entire width of the trace. Target pips appear as horizontal lines of length equal to a few degrees of bearing.

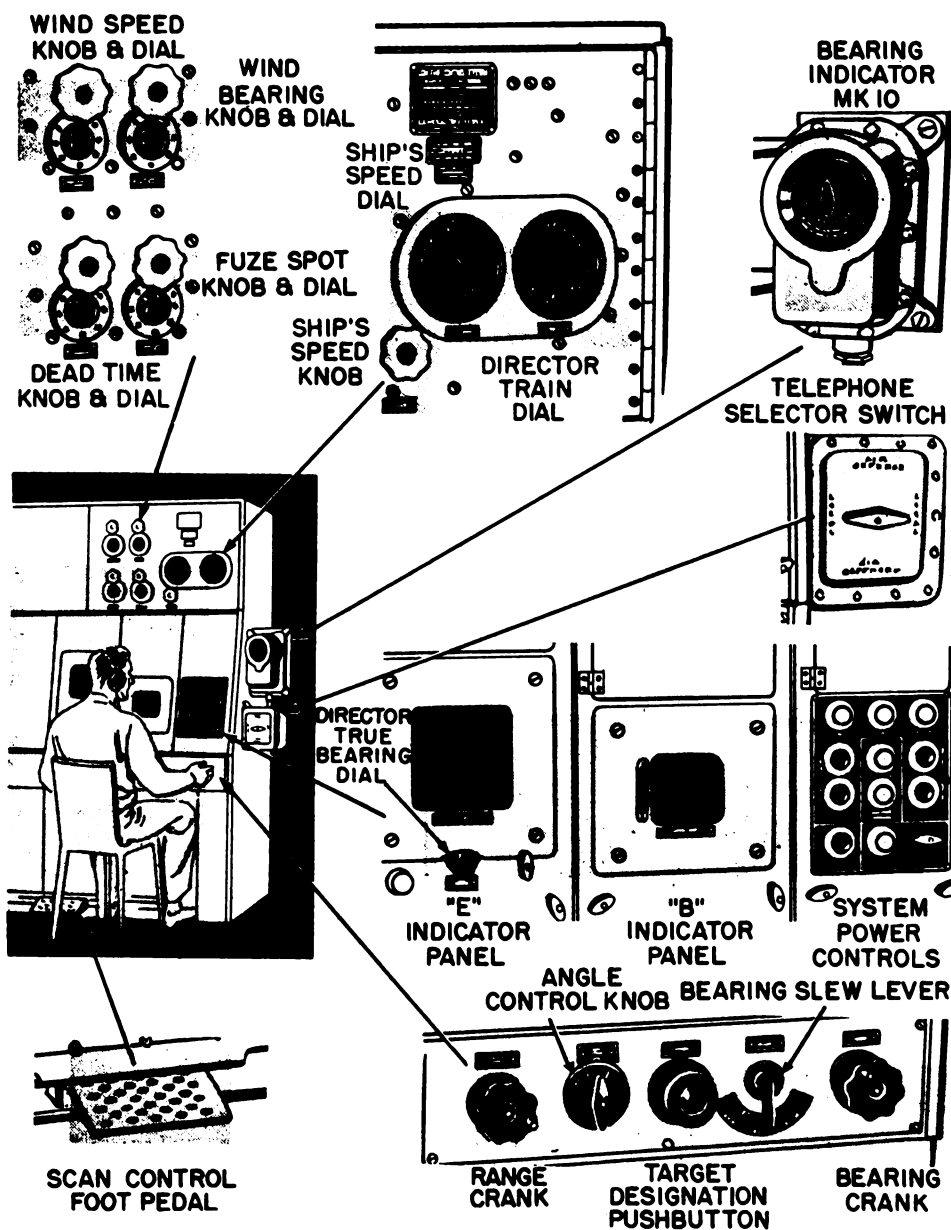


Figure 4-31.—Radar tracker's controls.

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For the pip to be visible on the B-scope, the range mark must be within 1000 yards of the target pip. When the radar tracker sees the target in the B-scope, he turns the range crank to bring the pip up or down to the range line, and simultaneously turns the bearing crank to bring the pip right or left to the director bearing line.

Figure 4-33 shows the appearance of all three radar scopes for different positions of

the target. The equipment is tracking target C; therefore the pip from target C is against the range mark on the A-sweep, at the step on the R-sweep, at the center of the trace in the E-scope, and at the center of the B-scope. All targets covered by the spiral scan appear on the A-sweep and E-scope. Target E does not appear on any scope because it is too far from the antenna axis. Target A does not appear on the B-scope because it is more than 1,000 yards

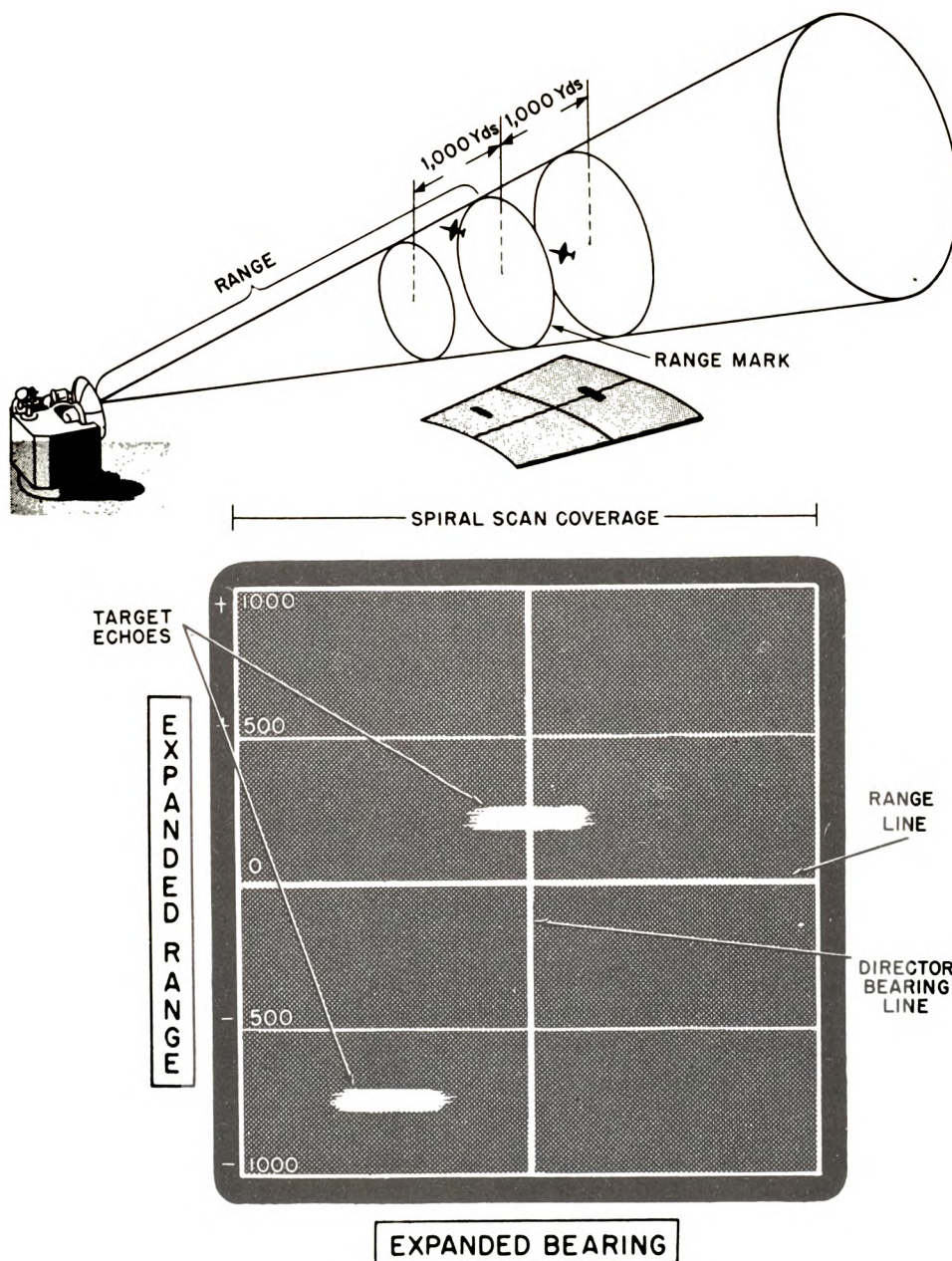


Figure 4-32.—B-scope presentation.

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from the range mark. Targets A and D do not appear on the R-sweep because they are more than 500 yards away from the range mark.

3. The telephone-selector switch. By means of this switch, the radar tracker can talk on either the air-defense circuit or the local circuit. Normally, he stays on the air-defense circuit. He switches to LOCAL to communicate with the director operator or gun captain.

4. The range crank positions the range mark on the target pip. One revolution of the crank changes the position of the range mark by 100 yards.

5. The bearing slew lever slews the director in train.

6. The bearing crank positions the director in train. It is used for more sensitive control

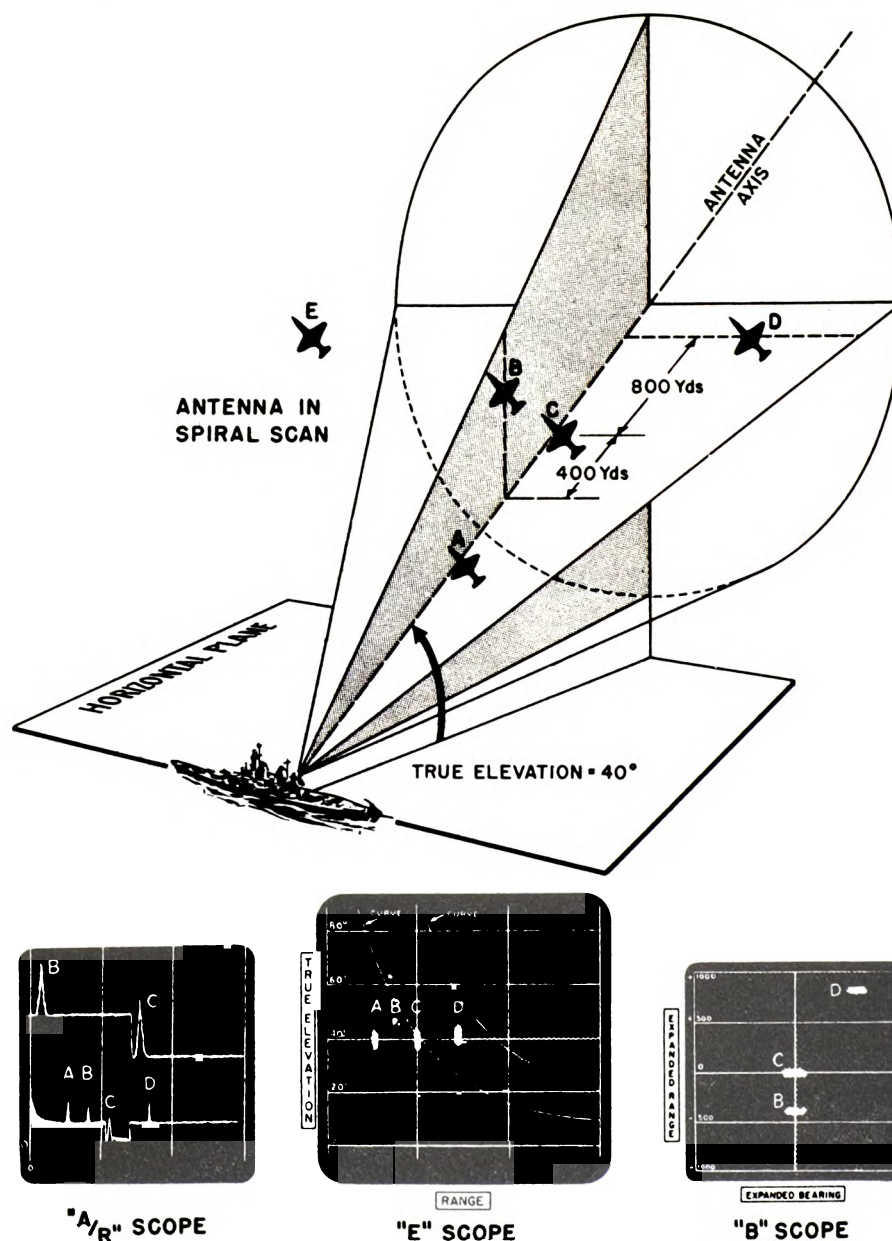


Figure 4-33.—Interpretation of radar scopes.

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of director train than is provided by operating the slew lever.

7. The angle control switch is used for radar tracking of surface targets. With this switch on SURFACE, the director is automatically positioned at 0° true elevation by a fixed signal, and the automatic tracking circuits are cut out. Tracking in bearing is performed by means of the bearing crank, which, in this

case, is operative both in conical and in spiral scan. The switch is usually left on NORMAL.

8. The target-designation push button, when pressed, automatically synchronizes the director with designated target bearing and range.

9. The scan control pedal controls antenna scan when the scan control switch is on FOOT SWITCH. The radar tracker selects SPIRAL

when searching and CONICAL when tracking. To change from one to the other, he presses the pedal which is a sequence-type ("press-to-change") switch. The only visible indication of whether the pedal is on SPIRAL or CONICAL is the width of the trace on the radar indicators.

Operation of the automatic tracking circuits is interlocked with the type of antenna scan. Automatic tracking in bearing, elevation, and range is possible only in conical scan. Also, automatic gain control normally depends upon conical scan.

In spiral scan, only manual tracking is possible. The elevation slew lever and hand crank and the bearing slew lever and hand crank are not operative in conical scan except when the angle control switch is on SURFACE.

10. The director bearing dials. The radar tracker receives indications of director bearing from three dials. The true-bearing dial on the E-indicator panel shows the bearing of the director from true north. The director-train dial on the console right-hand dial panel shows relative director bearing, and designated relative target bearing. Bearing Indicator Mk 10, attached to the right side of the console, shows both true and relative director bearing on the same dial face.

When bearing is designated, the tracker may slew the director to match the zero of the director-train dial with the designated bearing pointer. Normally, this is done automatically by pressing the target-designation push button.

11. The ship-speed knob and dial is used to set ship speed into the computer. The radar tracker sets this value into the computer by matching pointers. Normally, this is set automatically by a servosystem.

12. The wind-speed and wind-direction knobs and dials. The radar tracker sets true wind speed and true bearing of true wind into the computer manually, in accordance with values received by telephone.

13. The dead-time knob and dial. The radar tracker sets dead time into the computer manually by turning this knob. The dial is graduated in seconds from 2 to 6.

14. The fuze-spot knob and dial. By means of this knob, the radar tracker manually introduces range-spot corrections, from the control officer or the radar operator.

SUMMARY OF OPERATIONAL CONTROLS

All signals for positioning the director are introduced to the gyro unit, where they are

combined with the stabilizing signals and then transmitted to the director drives.

The slew switch takes precedence over all other switches. When on SLEW, it allows only the signals from the slewing sight to be introduced to the gyro unit. For any other unit to have control, the slew switch must be on LOCK.

Next in importance after the slew switch is the radar-optical switch. When on OPTICAL, it selects only the signals from the tracking control unit; when on RADAR, it allows signals from the console to take over.

The target-designation push button takes precedence over all other console controls. When pressed, it selects the designated bearing signal from the target-designation station and a fixed signal of 0° true director elevation or, on later systems, a designated elevation signal. On NORMAL, the target-designation push button allows other console controls to operate.

With the angle control switch on SURFACE, the director is positioned at 0° true elevation; in bearing, the director is positioned by operating the bearing crank or bearing slew lever.

When the bearing slew lever is being operated, signals from the bearing crank are cut out; the bearing crank is operative only if the slew lever is on NORMAL. Similarly, the elevation crank is operative only if the elevation slew lever is on NORMAL. When the angle control switch is on NORMAL, these slew levers and cranks are operative only in spiral scan, the scan control pedal serving its auxiliary function of choosing between manual and automatic tracking.

Automatic tracking is possible only in conical scan. The memory circuits are substituted for the automatic tracking circuits when the coast push button is pressed. The automatic tracking circuits will control the director if: (1) the coast push button is on NORMAL; (2) the scan control pedal is on CONICAL; (3) the angle control switch is on NORMAL; (4) the target-designation push button is on NORMAL; (5) the radar-optical switch is on RADAR; and, (6) the slew switch is on LOCK.

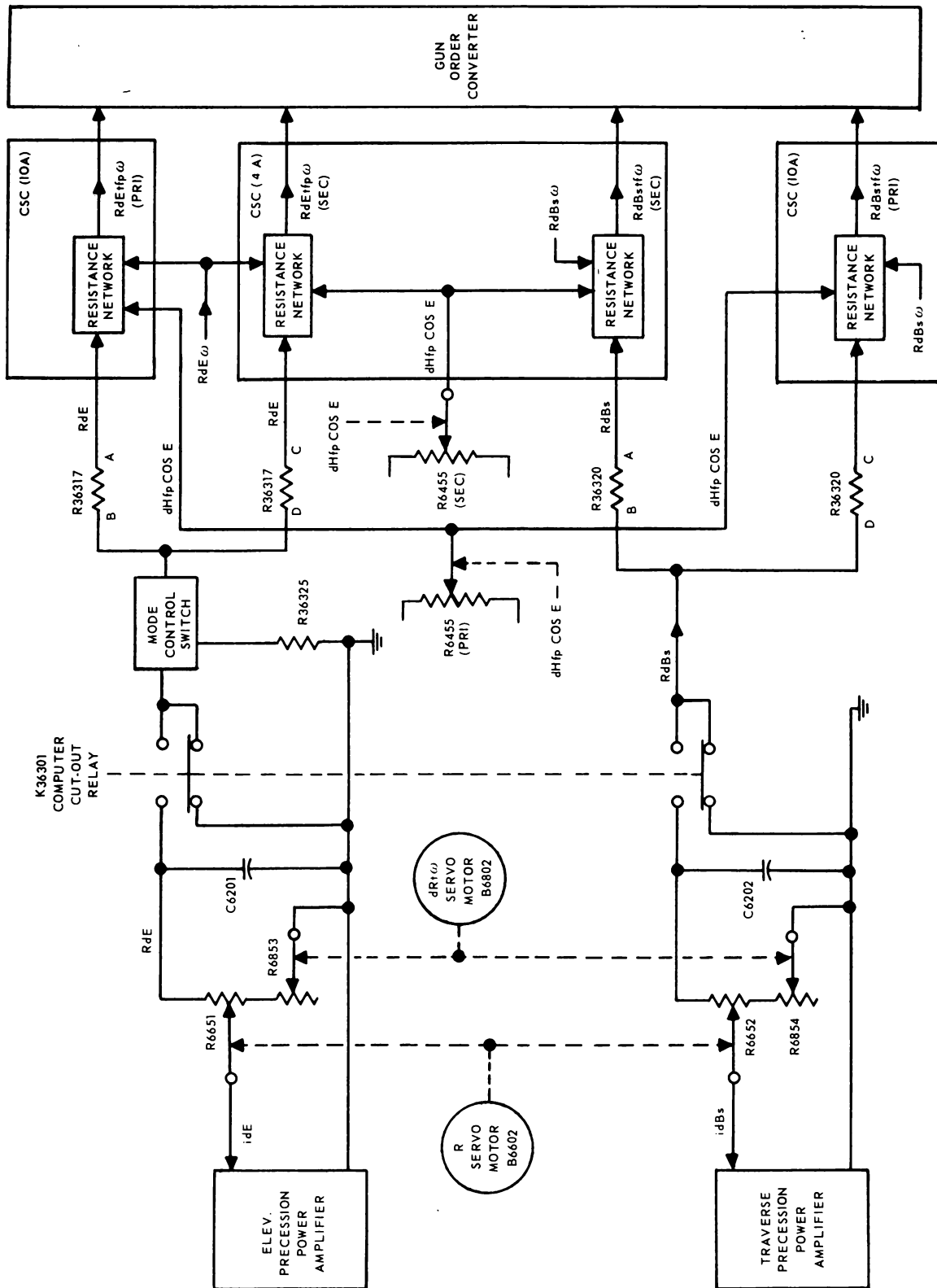
COMPUTER MODE SWITCHING.—The elevation and traverse rates introduced to the computer for computing lead angles are the same as those transmitted to the gyro unit for positioning the director. However, the computer does not receive slewing rates nor, generally, rates from the console cranks.

The only traverse and elevation rates received by the computer are those from: (1) the tracking control unit, (2) automatic tracking circuits, (3) memory circuits and, (4) in a special setting for surface fire, the bearing crank and zero elevation circuit. The rate from the bearing crank is introduced to the computer only if the scan control pedal is on SPIRAL and the angle control switch is on SURFACE (although it will be transmitted to the gyro unit to position the director regardless of the type of scan control when the angle control switch is on SURFACE).

In order to introduce any one set of these rates to the computer, the computer mode switch must be on NORMAL. Lead angles are computed from these rates, ballistic corrections added, and the total lead angles transmitted to

the gun order converter, where they are combined with director train and elevation. The resultant gun orders are then transmitted to the gun. With the computer mode switch on LOW-ANGLE TARGET, gun orders are produced in the same manner, the only difference being that any elevation rate input is cut out and a zero elevation rate substituted.

When the computer mode switch is on MANUAL INPUT, all rate inputs are cut out and the computer calculates no ballistic corrections. Instead, the manually introduced values of sight angle and sight deflection are introduced to the gun order converter in place of the total lead angles. Sight angle and sight deflection are combined with director train and elevation to produce gun orders.



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Figure 4-34.—Simplified schematic diagram of the elevation and traverse circuits.

CHAPTER 5

DIRECTOR AND ANTENNA POWER DRIVES

DIRECTOR AND ANTENNA POWER DRIVES

INTRODUCTION

The primary function of the director is to establish and maintain the target tracking line. Radars with automatic tracking features have become an integral part of the director power drives. The radar provides tracking signals to the director, which in turn keeps the radar antenna pointing at the target. In all methods of director control the tracking signals are separated into two components—the train control signal and the elevation control signal. This, of course, is fundamental, and familiar to you.

In some installations, such as the GFCS Mk 63, the radar has its own antenna positioning system. The director power drives and the antenna positioning systems are servosystems,

and therefore operate on familiar principles. Due to the large number of variations in installations, the emphasis will be placed on common features, most of which find their roots in servosystem principles. Let's examine a director power drive familiar to us, and look for servosystem concepts.

AMPLIDYNE POWER DRIVE

An amplidyne power drive is covered in the FT2 course, NavPers 10174-A. Figure 5-1 is a simplified diagram of the closed loop within this type of power drive. The diagram does not include stabilizing feedback circuits, but the basic servosystem principles are illustrated. We are controlling a large amount of power with a small order signal. The order signal is a command to the servo (short for servosystem) indicating a required condition. The error signal is the difference between the ordered

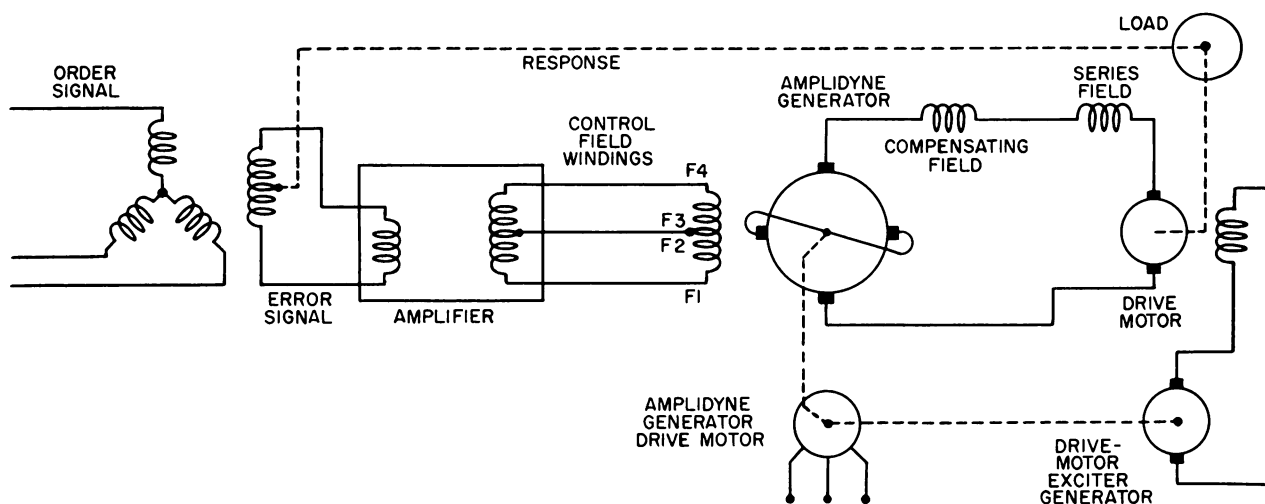


Figure 5-1. —Simplified diagram of the closed loop in an amplidyne power drive.

condition and the actual condition of the servo's output, in this case director position. The error signal is amplified by the amplifier and the amplidyne generator. The output of the generator controls the power motor which moves the director. The position of the director is fed back by the response line to the comparator, where it is compared with the ordered movement. When the director position equals the ordered position, the error signal is zero. This is a thumbnail sketch. Now we will go back and fill in some of the details, starting with the types of order signals.

TYPES OF ORDER SIGNALS

To establish the line of sight, (LOS), the director power drives must drive the director to an ordered position. To maintain the LOS on target, the power drives must move the director at a velocity equal to the relative target velocity about the LOS. Thus there are two fundamentally different types of order signals: position orders and velocity orders. Both have inherent advantages and disadvantages.

POSITION CONTROL

A position order signal represents a desired angular position of the director. Target position is a measured quantity; the initial source of the signal is a measuring unit, such as another director or a search radar via a designation system. The error signal is obtained by comparing the desired position of the director with its actual position. Hence the error signal is a measure of the LOS displacement. Velocity is not a part of the signal, but a mechanical factor which is a function of the drive's gain. As the amplitude of the error signal increases, the drive's velocity increases.

In position control the displacement is known; this type of control can position the LOS accurately. Thus position control is used to initially establish the LOS. But when tracking a target the drive must follow a dynamic signal, equal to the sum of target motion and own ship motion about the LOS. For this type operation a velocity signal is normally used.

VELOCITY CONTROL

A velocity signal represents the ordered velocity of the drive to maintain the LOS on

target. The error signal is the difference between the ordered velocity and the actual velocity of the drive. Hence the error signal is proportional to a change in velocity, or an acceleration signal.

The origin of velocity signals is somewhat more complicated than of position signals. Targets are capable of independent random motions, and their velocity cannot be measured directly. Targets, moreover, are not so cooperative as to tell us their course and speed. The elevation and bearing tracking rates, which equal the director power drives velocity signals, are extracted from target position information. Target position is measured continuously; therefore, the rate of change of position is available. Velocity signals are obtained from a device or system which can measure positional changes as a function of time.

The principle of extracting velocity information from position information is used in one form or another in all systems. The origin of velocity orders can be understood by considering the tracking procedure of the GFCS Mk 37. This system was covered in the FT2 course. The director measures target position and transmits this information to the computer. The computer uses the position information to solve for the relative rates of motion, and integrates the rates to derive a time rate of change of position signals. These signals are velocity signals, and are sent to the director to drive it at the computed rates. The director compares the target's observed rate of change of position with the computed rates. If these rates are not in agreement, a position error is detected by the director. The director corrects for the displacement of the target from the LOS; in so doing, it sends to the computer the target's new position, and an input to the rate control system which is proportional to the correction. The rate control system changes the computed rates to bring them into agreement with the observed rates. Tracking is a continuous procedure; therefore, the displacement error is never large.

We can summarize the Mk 37 system's approach to determine tracking rates (which are velocity signals) in this manner. The director measures the position of the target continuously. The tracking rates are computed and integrated with time. The integrated quantities equal the computed time rate of change of the LOS. The computed rate of change of the LOS is checked

against the observed rate of change. A change in the relative position of the LOS is a result of relative motion. Since own ship's motion is known, an error in the tracking rates must be caused by an error in the target motion computation. The result of a velocity error is a position error. The computer uses the corrections to the position error to correct the computed rates. This round robin continues until the computed tracking rates are correct. Later in the chapter, when we cover gyros in power drives, we will describe other approaches used to obtain velocity signals.

The disadvantages in velocity control are found when we use a velocity signal to drive the director to a desired position. To do this, time must be known since position equals the product of velocity and time. The drive, however, does not know the time factor, so it must be supplied from an external source. This is a major disadvantage of a velocity control drive.

Most director drives have both velocity and position control systems. The director is driven to a designated position by a position order signal. Once tracking is started, the director is shifted to a velocity order signal.

SIGNAL GENERATORS

Most signal generating devices are capable of originating either position or velocity signals. The signal output is determined by the device's associated units. The theory and operation of these devices are covered in previous courses.

POSITION SIGNAL GENERATORS

Position orders are originated and transmitted by devices which measure displacement. A position signal generator measures movement from a reference point. The unit of measure may be changed (minutes of arc to mils), but the output is directly proportional to displacement. Time is not a factor; the device measures the displacement as it occurs. Here are a few examples of the more widely used of these devices. This is by no means a complete list.

SYNCHROS and RESOLVERS.—The output signal of these devices is a measure of the displacement between the rotor and the stator. The stator normally establishes the reference point. The rotor's offset from the stator is proportional to the displacement of the signal from the reference. An example of synchros or resolvers used as position signal sources is in interdirector designation. The designating director transmits its position via synchro signals. The receiving director drives to the designated position. Velocity and time are not involved.

POTENTIOMETERS.—The output of a potentiometer is proportional to the displacement of the wiper arm from a reference point on its winding. A balanced bridge circuit (fig. 5-2) illustrates a potentiometer as a position signal generator.

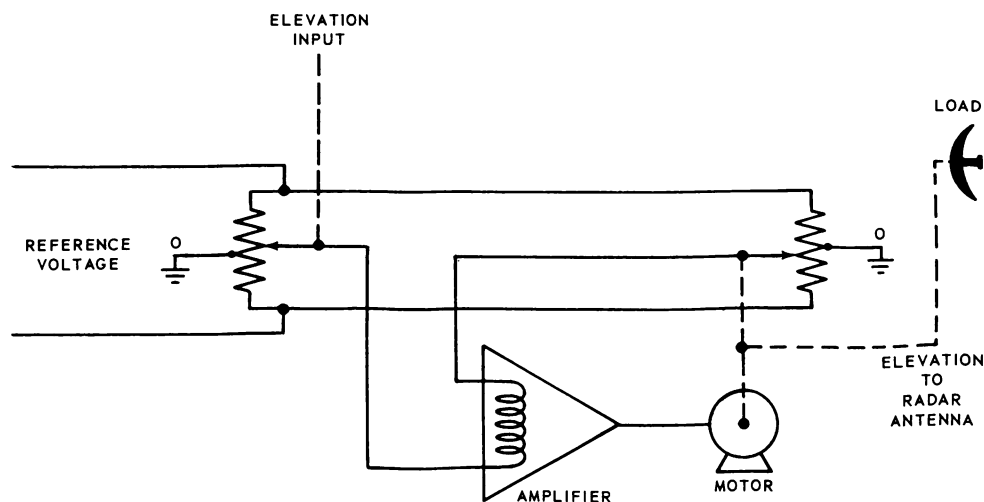


Figure 5-2.—Balanced bridge circuit.

TRANSFORMERS.—Pickoff and crossed-E transformers working in conjunction with a gyro may have an output voltage proportional to displacement. As an example, we will use the Stable Element Mk 6. The sensitive element contains a two-degree of freedom, vertical-seeking gyro which maintains itself in the stabilizing horizontal plane. The output of the stable element is the displacement of the deck plane from the horizontal plane. A transformer, whose primary is located on the gyro unit and whose secondary windings are attached to the gimbal assembly, generates a voltage proportional to the displacement.

VELOCITY SIGNAL GENERATORS

Velocity order signals are originated by devices which compute the rate at which a position is changing. Since target velocity cannot be measured directly, velocity order signals are related to the timed movement of the LOS, which can be measured. Hence an identifying feature of a velocity signal generator is that its output is a function of time and movement. The devices which follow are a few of the velocity order signal generators.

SYNCHROS AND RESOLVERS.—These devices were listed under position signal generator, since they measure displacement from a reference point. As velocity signal generators they still measure displacement, but the movement causing the displacement is timed by an associated unit. As an example, we will use the generation of elevation in the Computer Mk 1A. The elevation synchro generator is connected to the output shaft of the elevation integrator (fig. 5-3). The integrator multiplies the computed elevation rate by a function of time. The integrator's output is a mechanical rotation which represents increments of motion. The sum of

the increments for a time period is equal to the computed amount of elevation displacement for that period. Thus the increments are equal to a timed movement or a velocity signal. The synchro generator transmits this quantity to the director's elevation drive. The synchro transmission system could be replaced by a resolver system.

TACHOMETER GENERATOR.—You are familiar with tachometer generators (tachs) as velocity feedback devices in the stabilizing circuits of servos. Here we will use them as velocity order generators. A tach's output voltage is proportional to a rotary velocity. The amplitude of the voltage is proportional to the speed of rotation, while the phase or polarity of the voltage indicates the direction. Speed plus direction is equal to velocity. Note that the tach measures a velocity in an electrical form but does not compute the velocity. An associated timing unit is necessary for computation. We could substitute a tach for the synchro in figure 5-3.

DIFFERENTIATING CIRCUITS.—These are electrical networks consisting of a combination of resistors and capacitors forming an RC circuit. From your study of radar special circuits you know that a differentiating circuit produces an output voltage proportional to the rate of change of the input voltage. This type of circuit can extract a velocity signal from a changing displacement signal or an acceleration signal from a changing velocity signal. An explanation of RC circuits used in feedback circuits was given in the FT2 course. Here we are using the same circuits to obtain order signals. A description of a drive using an RC circuit to obtain velocity signal is given in chapter 3 of this course.

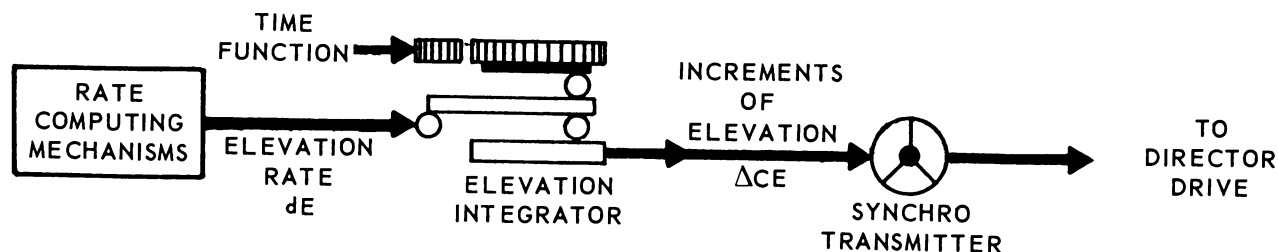


Figure 5-3.—Generated elevation velocity signal.

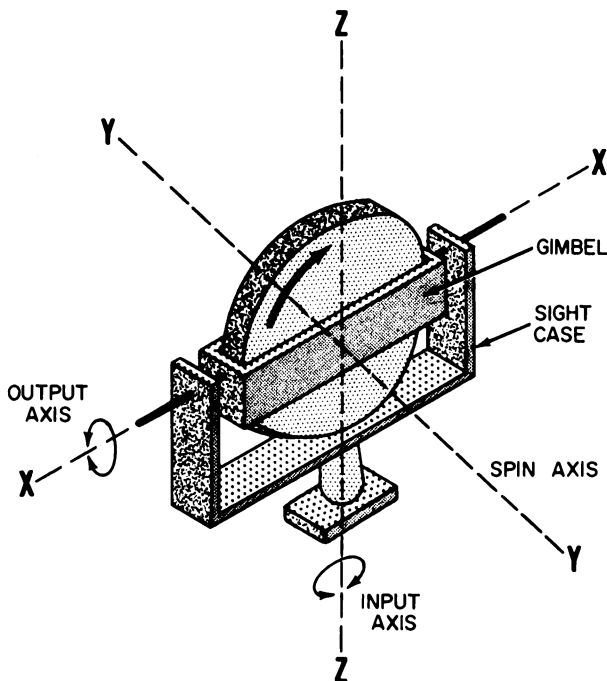
POTENTIOMETERS.—A potentiometer transmits a velocity signal when the wiper arm displacement is made proportional to a velocity. The drive explained in chapter 3 contains a potentiometer which transmits a velocity signal.

GYROS

Gyros are used extensively in director drives, and their functions vary. Therefore we will discuss in depth the applications of gyros as measuring devices and signal sources in power drive systems. It is assumed that you are familiar with the two-degree of freedom or universally mounted gyro and the single-degree of freedom or restrained gyro. And it is assumed that you understand the properties of a gyro—rigidity of plane, precession, and translation. This knowledge is required, since we will review here only so far as it serves our purpose.

SINGLE-DEGREE OF FREEDOM GYRO

The single-degree of freedom gyro has three mutually perpendicular axes: a spin axis, a sensitive (input) axis, and a precession (output) axis (fig. 5-4). A torque applied to the sensitive



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Figure 5-4.—Single-degree of freedom gyro.

axis of the gyro, by turning the structure on which it is mounted, will cause the gyro to precess about its output axis. Torque applied in any other direction will not precess the gyro since the gyro is restrained in all other directions. The gyro precesses in an attempt to find a plane of rotation in which the applied torque balances the gyro's internal inertial force.

The relationship between the amount of precession and an applied torque is determined by the gyro's precessional resistance. Because the gyro wheel's internal resistance (angular momentum or inertia) is constant, its precession is directly proportional to the input torque. In the equipment, the torque is developed by angular motion of the gyro's sensitive axis; therefore, gyro precession is a measure of the rate of motion of this axis. Since we are dealing with a velocity, time is a factor. Time is represented in the gyro by its precessional resistance. The gyro wheel's internal resistance is comparatively small, so more resistance in the form of damping is added. Where the damper's resistance is constant it will represent time in the gyro. In some installations the resistance is variable and represents a function of time—time of flight for example.

The torque (velocity) acts against the resistance (time); thus the gyro integrates the velocity with time. The product of velocity and time is displacement. The integration process of the gyro is identical to the process used by the mechanical integrator in the Mk 1A computer. The integrating gyro has the advantages of being able to measure the velocity directly and of precessing in proportion to the velocity, thus furnishing a direct measure of displacement. We will apply the integrating gyro to an antenna positioning system and a director with automatic tracking radar. After these examples we will discuss a variation by using the gyro to solve for a rate rather than a displacement.

ANTENNA POSITIONING SYSTEM

We will use the GFCS Mk 63 with the Lead Computing Sight Mk 29 to demonstrate the integrating gyro. Remember, we are discussing the gyros in the sight and not the complete system or sight. The system was covered in a previous course. We will restrict the discussion to the traverse and elevation gyros. The operation of these gyros is identical.

There are two types of torque applied to the gyros. One torque is proportional to the angular rate of motion of the director in the sensitive plane of the gyro. This torque will cause the gyro to precess an amount which depends on the strength of the torque and the gyro's resistance to the torque. The gyro's dampers provide a constant amount of resistance to precession, and the range springs a variable amount (fig. 5-5). The variable resistance modifies the gyro's output to compensate for changes in range—time of flight. The output of the gyro is proportional to angular velocity and a time function. Hence the gyro has effectively integrated the director's angular rate with a time function to obtain a displacement equal to the relative motion lead angle.

When a smooth track has been established, the gyro has precessed enough to reach a balance between the applied torque and gyro resistance. The gyro will remain precessed a constant amount. Under these conditions if the angular rate (torque applied) changes, the gyro will precess to a new value which is proportional to the new rate. In effect, the precessional change is determined by the change in the torque. Therefore, the gyro has differentiated the changing velocity signal to obtain an acceleration signal which it uses to change the precessional angle (lead angle). A change in gyro resistance (range) would result in a change in the precession angle in the same manner as a change in the torque.

The second type torque is applied in the output axis of the gyro. In this axis the torque will not cause precession; but the torque uses brute force to tilt the gyro. Since tilt is in the output axis, the only axis it can be in, we will call it precession. The torque is applied by weights and torque motors. Here we will only consider one of the motors. The torque applied to the gyro is proportional to the current in the motor, which in turn is proportional to a

computed wind correction offset. The torque acts against the gyro resistance. Thus, gyro precession is proportional to the integral of the wind torque signal and a time function.

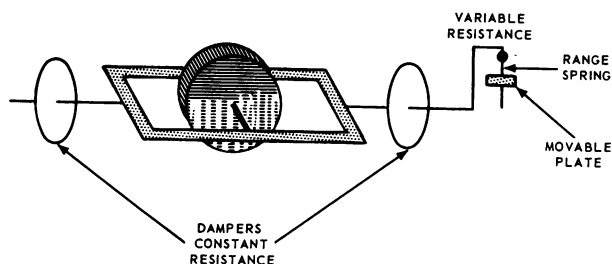
The total precession of the gyro is proportional to the algebraic sum of the applied torques. The precession is a displacement signal which mechanically offsets the sight's optical system from the sight case axis. The offset results in the sight case axis being positioned in the line of fire (LOF). The sight's optical system remains in the LOS. The radar antenna is located on the gun mount. The gun mount is positioned in the LOF by the gun drive. Thus the antenna must be offset from the LOF into the LOS. This offset is equal and opposite to the optical offset in the sight. A pickoff transformer mounted on the gyro's output shaft measures the precession angle and produces an electrical signal proportional to it. This signal is amplified and is used to drive the antenna into the LOS.

DIRECTOR DRIVE

The director drive works in conjunction with an automatic tracking radar, that is to say, a lock-on radar. The radar furnishes displacement signals to the drive. These signals indicate the position of the target with respect to the antenna axis which coincides with the LOS. The LOS is stabilized.

Two gyros, an elevation gyro and a traverse gyro, are mounted in the moving section of the radar antenna (director). The orientation of the gyros with respect to the LOS is shown in figure 5-6. The spin axes of the gyros are parallel to the LOS. The input axis of the elevation gyro is in the horizontal plane and parallel to the antenna's elevation axis. The traverse gyro's input axis is in the vertical plane and parallel to the antenna's traverse axis. It follows then that the elevation gyro will be affected only by an angular motion about the elevation axis of the antenna and the traverse gyro by an angular motion about the antenna's traverse axis. The operation of both gyros is similar; therefore, only the operation of the elevation gyro will be described.

A torque motor and a signal generator are located on the gyro's output shaft, (fig. 5-6). The torque motor is connected to the radar receiver's angle tracker. The angle tracker provides signals to the torque motor which are proportional to target displacement from



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Figure 5-5.—Resistance to gyro precession.

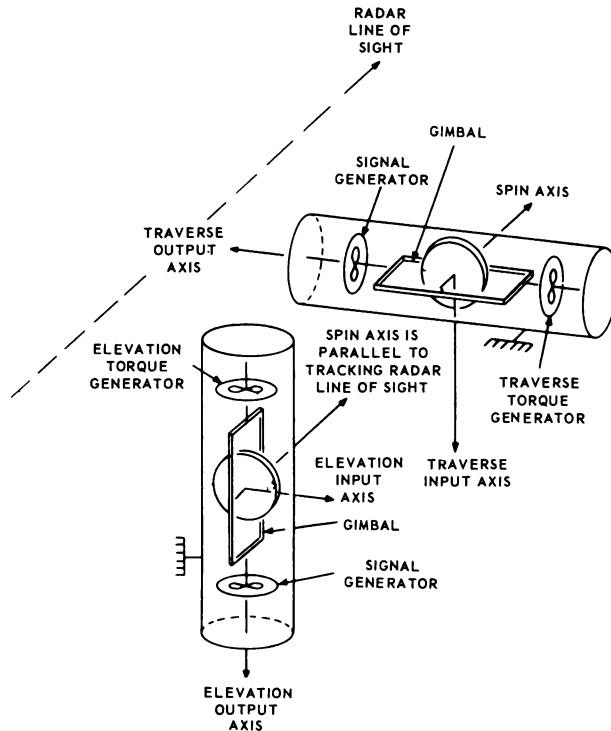


Figure 5-6.—Orientation of gyros.

the antenna boresight axis. The control current in the motor and its output torque are proportional to target displacement. The motor precesses the gyro in a direction and in an amount directly related to the tracking signal received by the motor. The signal generator on the gyro produces an electrical signal proportional to gyro precession. This signal is transmitted to the director as a control signal for the director's elevation power drive. The drive changes the velocity of the antenna to reposition its boresight axis on target. The movement of the director produces a torque on the gyro in a direction to nullify the precession caused by the torque motor. The conditions now are: the antenna is on target; the director is moving at the correct velocity; the elevation gyro is in its neutral plane parallel to the elevation axis; and the system is ready to repeat the procedure when necessary.

Let's compare the 63 system with this director drive system. In the 63 system the tracking rate is the input to the gyro. The gyro precesses and remains tilted in proportion to the rate. The wind input on the torque motor adds to the gyro precession. In the

director drive the initial tracking input is a displacement signal. The angular motion of the director produces a torque to null the torque motor input and the gyro's tilt. In this system unless there is a tracking error the gyro is not tilted.

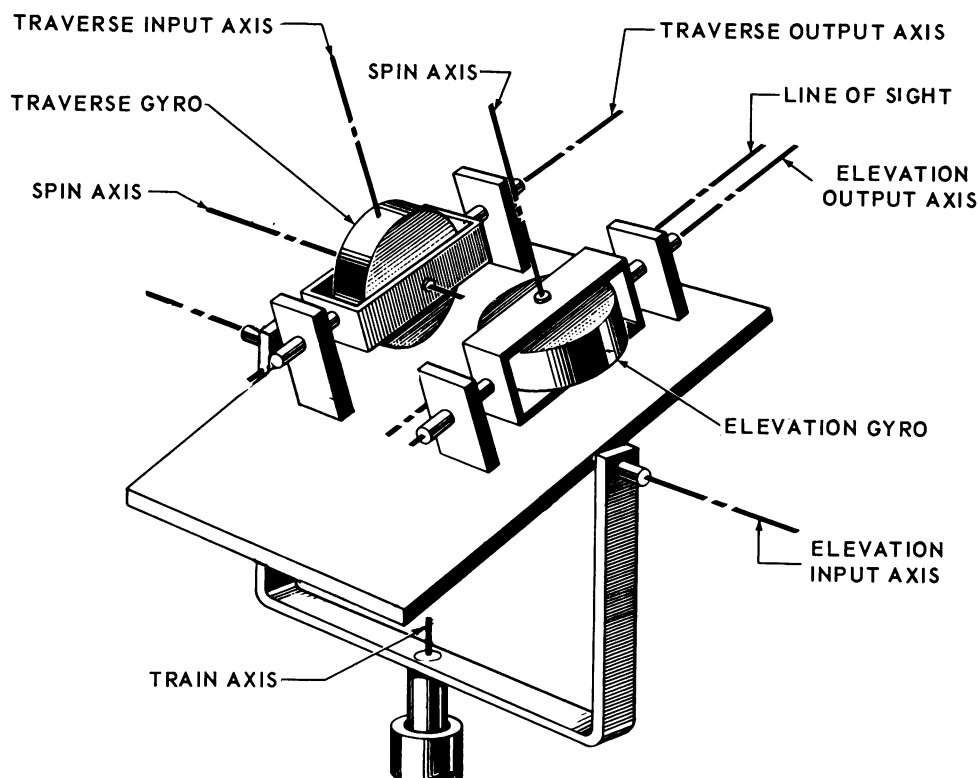
Let's see what the effect of ship's roll and pitch is on the tracking system. The gyro is in its neutral plane parallel to the elevation axis, and will detect any angular motion about this axis. Consequently, a movement of the ship will result in gyro precession. The gyro will precess an amount proportional to the rate of angular motion, regardless of whether the drive or the ship causes the motion. The gyro's signal generator sends a signal to the director which moves the antenna in the opposite direction to the ship's movement. The director motion produces a torque on the gyro which will nullify the precession causing the motion. Thus the gyro is again back in its neutral plane from which it will provide a stable platform for tracking.

RATE MEASURING GYRO

In the third variation of single-degree of freedom gyros the output of the gyro is the rate of motion of the director. The gyros are oriented with respect to the LOS as shown in figure 5-7. Each gyro measures the rate of motion about its sensitive axis. The two gyros are similar in operation. Their function is determined by the plane in which they are mounted. Therefore, only the elevation gyro will be explained.

The elevation gyro provides a velocity response signal to the director drive and stabilizes the LOS in the horizontal plane. Initially, the control signal to the elevation drive is a velocity signal from the computer. The velocity signal is extracted from target displacement signals sent to the computer from an automatic tracking radar. The computer uses differentiating circuits to obtain the velocity signal from the displacement signals. Hence the director is moving in elevation at a computed rate.

The elevation gyro has a torque motor and a signal generator mounted on its output shaft. The signal generator is connected to the torque motor through the amplifier (fig. 5-8). The gyro detects the motion of the director in elevation and precesses an amount proportional to it. The gyro's signal generator produces a signal



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Figure 5-7.—Orientation of gyro axes.

proportional to the amount of precession. Consequently, the signal is a measure of the elevation rate. The signal is amplified and applied to the torque motor and a summing network in the elevation power drive. The phase of the signal is such that the output torque of the torque motor is in the opposite direction to the precessional torque, and the signal's magnitude is such that the torque motor's output will balance the precessional torque. When this occurs the signal is an accurate measure of the elevation rate. In the summing network this signal is in

series opposition with the computer's velocity signal, and tends to null it. This arrangement allows the use of a high gain amplifier in the power drive. This results in improved dynamic response to an acceleration signal.

When ship's roll or pitch causes an angular motion about the elevation axis, the gyro detects this motion and precesses. The precession is the same as if the motion were caused by the power drive rather than by the entire ship moving. Since the gyro's signal generator output is in opposition to the motion which caused the precession, the gyro reacts in the same manner as for power drive motions. Consequently, the gyro furnishes the system a stable platform for tracking.

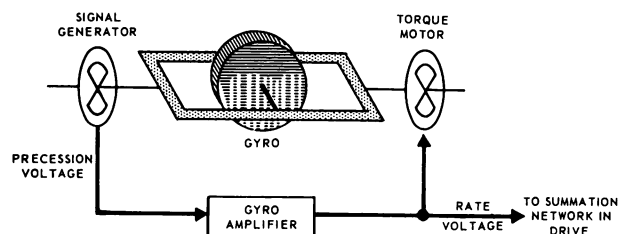


Figure 5-8.—Rate-gyro.

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TWO-DEGREE OF FREEDOM GYRO

The two-degree of freedom gyro used in tracking systems relies on its rigidity in space to establish reference planes from which target displacement signals are measured. This, of course, is stabilization. The gyro does not

precess. It remains horizontal, and measures the displacement of the deck plane out of the horizontal plane. This is the function of the stable element in the GFCS Mk 37 and the stable vertical in surface systems.

The GFCS Mk 56 uses two universally mounted gyros, one for stabilization and the other for rate computation. We will describe the operation of these gyros to complete the coverage of gyros in power drives. Here again, remember, we are not describing the entire system; a summary of system operation is covered in chapter 4.

The LOS is stabilized by the vertical gyro. The gyro is rigid with respect to space, and establishes the horizontal reference plane. The gyro's outer gimbal is elevated by the director's elevation system so as to maintain the gyro gimbal axes parallel to the LOS (fig. 4-21). This gimbal is in the slant plane and ship's motion across the LOS measured by the gyro is cross-traverse.

The rate gyro is a universally mounted gyro rigid with respect to a point in space. Target displacement signals from the tracking system (normally the automatic tracking radar), are fed to torque motors located on the gimbal shafts of the gyro. The torque motors precess the gyro an amount proportional to target displacement. Due to this precession the gyro's space reference point is shifted. A crossed-E transformer measures the precession in two mutually perpendicular axes and provides the director power drives with displacement signals to reposition the LOS in accordance with the gyro's new space reference. In effect, the gyro is pulling the director with it as it precesses.

CONTROL SIGNALS

Control signals from units such as a designation system, an automatic tracking radar, or a computer are inputs to the director's drives. Since there is a clear division between types of control, there is a clear division between control signals. Target position information is received by the fire control system from an external source, while tracking signals originate within the system. The director's mode of operation determines the type of control signal applied to its power drives. We will briefly describe the condition of the power drives and their input signals in each mode of operation. We will not deal with a

specific system but speak in general, although frequently a distinction between gun and missile systems is necessary.

MODES OF OPERATION

Fire control systems are integrated. Therefore the director, the radar, and the computer are in the same mode of operation. The mode of operation is shifted by system switching and relays in the control circuits of the units. Many of the control circuits are interconnected between units and are interdependent. For example, when an automatic tracking radar locks on target it automatically shifts to track and causes the director and computer to shift to the track mode.

The names given to the modes are descriptive of the director's operation. Note that the modes covered here correspond to the computer's mode of operation covered in chapter 3.

STANDBY OR AIR READY.—In this mode the director is ready for instantaneous operation. The drive is energized with the exception of plate supply voltage to electronic amplifiers and high voltages to the drive motors. The drive's power brakes are applied.

Some missile directors receive signals from their associated computer to direct them to a fixed air ready position. In these directors when the system is energized and no other mode control signal is present the director drives to the fixed position. Once the director is synchronized to the signal, relays deenergize the plate supplies and the high voltages, and apply the power brakes.

DESIGNATION OR ACQUISITION.—Upon proper system switching the director is shifted to the designation mode. In the designation mode the director drives are fully energized and the power brakes are off. The designation signal, a position signal, controls the drive. Designation sources vary greatly between installations. The normal source of designation is the WDS or the TDS. Fire control systems are interconnected to provide intersystem designation. Some stations transmit designation signals by synchros while others use resolvers. Hence it is sometimes necessary for a director to have both types of receivers. The correct type of receiver is selected by switches

in the system which operate relays in the director drive. The drive's operation is identical using either type receiver.

The director accepts the designation signals and drives to the designated position. Once synchronized, the director will follow any change in the signals. Since position signals are used in designation, separate channels or special circuits are provided to adapt the drives to accept this type of signal. Director drives are usually not self-synchronous except in the designation mode; in track mode a director follows rate signals from a position it has established. Directors which contain gyros normally cage the gyro during designation to eliminate damaging the gyros during rapid acceleration of the director.

The designation signal may be modified by a search signal. The search program moves the LOS about the designated position. In some systems the computer initiates the search program and signals while in other systems it is initiated in the director. In either case the director drives follow the designation signal plus any modifying search offset. In systems with pulse doppler radar the search program is correlated with the changes in the pulse repetition rate of the radar transmitter to avoid missing a target due to the radar's blind velocity. In these systems the computer sends rate signals to the director, along with the position signals. The rate signals overcome the director's inertia during search to ensure that the pulse repetition rate is always shifted at a particular point in the search pattern.

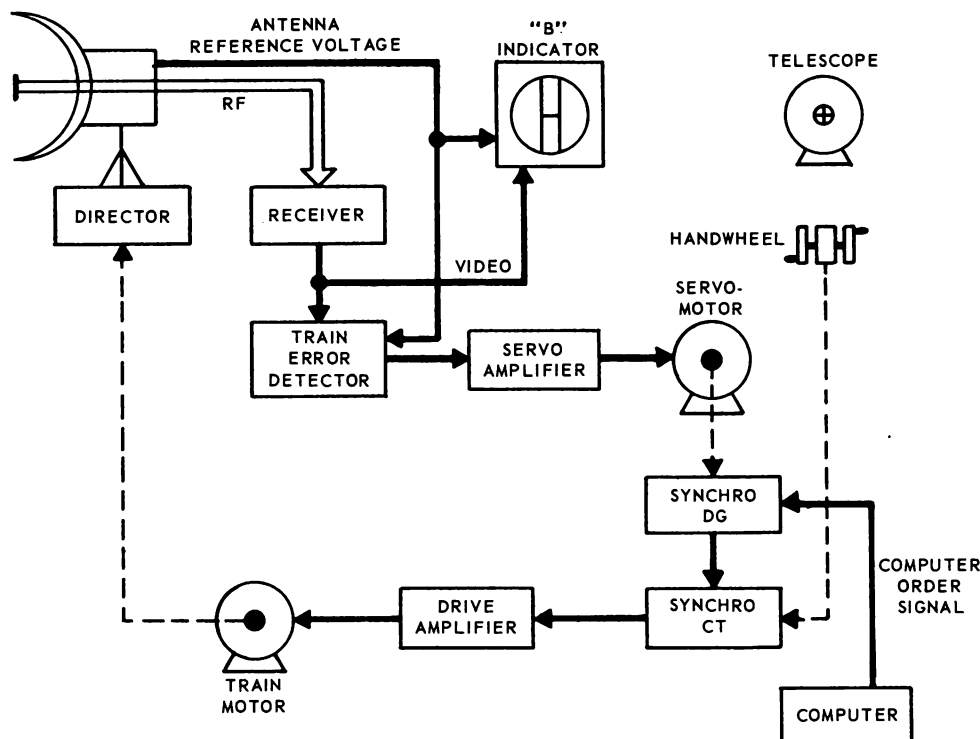
TRACK.—When the director acquires the target the system is put into the track mode. This is done by the radar locking on the target, or the director operators closing a key or switch. The position circuitry used in designation is decoupled from the director drive's amplifiers, and the track channel is substituted.

Tracking commences with the LOS on target. Tracking rates are obtained from measurements of target displacement from the LOS which develops during track. In optical control the director operators are the error detectors. The trainer, for example, observes the target through this telescope and turns his handwheels to keep the LOS on target (fig. 5-9). Movement of the handwheels is used in the computer to correct the tracking rate fed to the synchro differential in the illustration.

AUTOMATIC TRACKING RADARS produce voltages which are proportional to target displacement from the LOS. Hence the radar is the error detector. Elevation and train tracking systems are identical; therefore, only train is discussed. Figure 5-9 is a functional block diagram of the train system. The radar antenna is in conical scan. When the target is off the boresight axis of the antenna the r-f echo return is amplitude modulated. The magnitude of the modulation indicates the amount of target displacement, while the phase of the modulation indicates the direction of the displacement. The radar's error detector produces control voltages proportional to the modulation, and therefore to target displacement. The control voltage is amplified and used to drive the servomotor. The servomotor is mechanically coupled to the synchro differential which feeds the displacement signal to the CT in the director drive. The director drive moves the director (antenna) to eliminate the error.

STABILIZATION.—In the track mode the LOS is stabilized to compensate for the effects of ship's roll and pitch on the tracking problem. The correction signals necessary to stabilize the LOS are inputs to the director drives. Where possible the stabilization signals are added to the tracking signals. In systems which use gyros to establish the angular tracking rates the gyro also performs the stabilization function. The precession of the gyro caused by the roll and pitch of the ship is algebraically added to the precession of the gyro caused by target motion. Hence the corrections for stabilization are automatically incorporated in the director drive's control signals. Unless the antenna has an independent drive in the traverse axis, a third single-degree of freedom gyro is necessary to measure ship movement around the LOS. The necessity for a cross-traverse correction was covered in the discussion of the GFCS Mk 63 in the FT3 course. The cross-traverse signal from the gyro is sent to the computer where the director's train and elevation rate signals are corrected for the effects of cross-traverse movements.

Some systems, such as the GFCS Mk 37, have a stable element. This instrument measures the tilt of the deck plane out of the horizontal plane and produces level and crosslevel. Level, the correction for stabilization in the LOS, is added to the increments of elevation in the computer and thus is an input to the director's



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Figure 5-9. —Train tracking.

elevation drive. Since crosslevel affects elevation and train, it is sent to the director as a separate stabilization signal. The crosslevel drive moves the director optics and the radar antenna to compensate for crosslevel. This type of system was explained in the FT2 course.

COMPUTER AIDED TRACKING.—Computers which generate increments of relative motion of the LOS transmit this information to the director as an aid to keep the LOS on target. In figure 5-9, for example, increments of computed bearing from the computer are an input to the synchro differential in the radar. The output of the differential is the algebraic sum of the computer signal and the radar's target displacement signal. The output signal is the input to the synchro control transformer in the director drive. If the radar momentarily loses the target, the director will continue to move at the last computed rate.

In all systems the computer simulates the actual problem to solve for weapon orders. Thus the computed tracking rates of the LOS are available in computers which do not generate increments of motion of the LOS. These

systems are those which use gyros to measure or compute the angular rate of motion of the director. The rate signal in the computer is used to keep the director driving at the last computed rate when the target is lost by the radar.

Tracking is a closed loop. The director accepts designation and slews to the designated position. The radar acquires and then locks on the target. The director drives, working in conjunction with the computer and radar, keep the LOS on target.

LOCAL OR TEST.—Provisions are incorporated in the director drives to break the closed loop and operate the director locally. The local control signals originate in the director or at the radar console. Going back to figure 5-9, you can see that the handwheels can be used to furnish a local signal in this system. In the local mode of operation relays in the drive decouple the automatic signal from the drive and a local voltage is substituted. Not shown in the illustration but included in the drive is a slew sight for rapid acceleration of the director.

When the slew sight is deflected from its neutral position it varies the current to the field windings of a slew motor. Hence the amount of deflection of the slew sight controls the speed of the slew motor which is geared to the CT.

In some systems, local control signals are originated at the radar console. In some of these systems synchros located in the console are substituted by relay action for the computer's synchros. The position channel used in the designation mode is used in the local mode. The radar operator turns a handcrank connected to the local control synchros and drives the director to the desired position. Another method of originating local control signals at the radar console is to use a reference voltage proportional to the desired velocity signal. The radar operator has a joystick or handcrank with which he can vary the magnitude and the phase or polarity of the reference voltage. This voltage is substituted for the normal tracking signals.

Local control furnishes a means of local acquisition of targets using the fire control radar's scopes. The director drives can be tested independently of the radar's automatic tracking system and the computer.

RATE GYRO DIRECTOR DRIVE

Figure 5-10 is a functional block diagram of the traverse drive in a director which controls

gun and missile batteries. Since the director's elevation drive is similar to the traverse drive, only the latter is discussed. The drive has a position channel for designation signals and a velocity channel for track signals. The computer modifies the designation signals with search signals when necessary. The FC radar is a pulse doppler type; therefore, a velocity signal is sent to the director when it is in the search mode. This velocity signal uses the drive's normal velocity channel.

POSITION CHANNEL

The director accepts designation. The director's synchro control transformers compare the ordered position received from the computer with the actual position of the director and produces an a-c error signal proportional to the director's displacement. The error signal is amplified in the preamplifier and then rectified in the demodulator. The preamplifier is a conventional voltage amplifier and the rectifier is a conventional phase-sensitive demodulator. In the demodulator the phase and the magnitude of the error signal are compared with these values in an a-c reference voltage. The magnitude and the phase of the d-c output are determined by this comparison.

The error signal is rectified for use in the anticipation circuit. This is a fancy name for

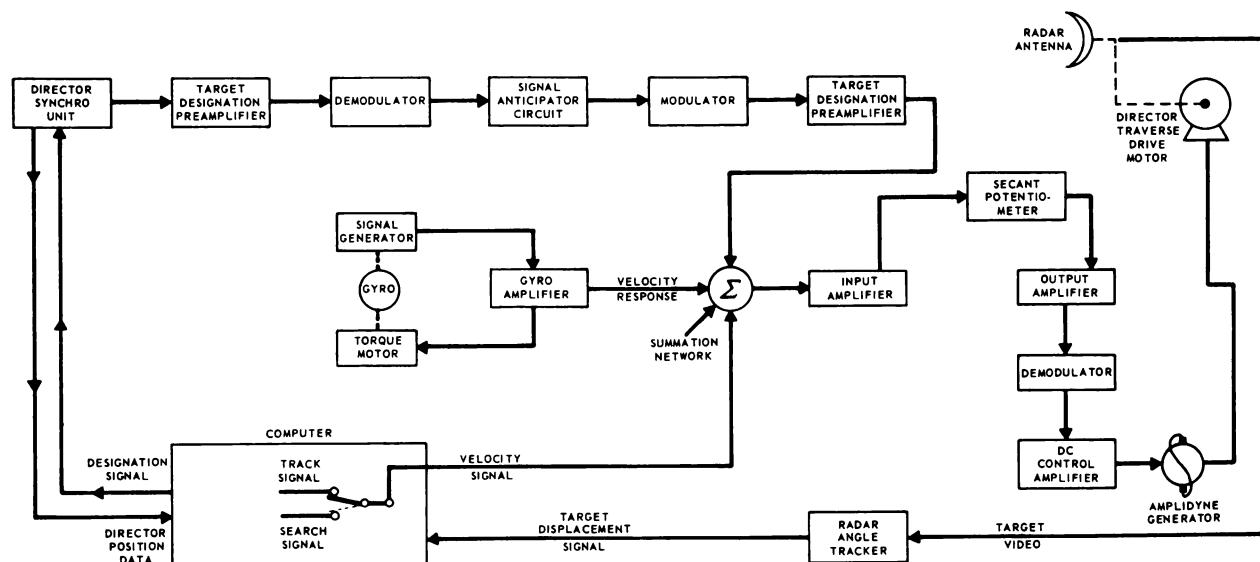


Figure 5-10.—Simplified diagram of rate gyro drive.

an error-rate circuit (RC circuit). An input with a constant magnitude to the anticipation circuit produces an output with a constant magnitude. This is the case for a large displacement error; the preamplifier is saturated and its output is constant. But as the drive comes into synchronism, or if the drive is synchronized and the designation signal is changing, the d-c error signal to the anticipation circuit will change in magnitude. The output of the circuit initially is larger than the change in the input warrants, because the capacitor in the circuit cannot react instantaneously to the voltage change. The anticipation circuit increases the sensitivity of the drive to a change in the signal. The d-c error signal is modulated back to an a-c voltage for amplification and summation.

The signal from the modulator is amplified in the preamplifier and then added to the search velocity signal from the computer and the velocity response signal from the gyro. From the connection in the illustration you can see that the gyro is used to measure the rate of angular motion about its sensitive axis. The angular momentum of the director causes gyro precession. The signal generator's output is proportional to the precession. This signal is amplified and then applied to the gyro's torque motor. When the output torque of the motor is equal and opposite to the torque which caused the precession, the gyro amplifier output is directly proportional to the director's angular rate. The gyro furnishes a velocity feedback voltage to the summing network.

The summation voltage is applied to the a-c amplifier. In the amplifier, the train error signal is converted to a traverse signal by multiplying it by the secant function of the elevation angle. The output of the amplifier is rectified in a phase-sensitive demodulator and the d-c traverse error voltage is applied to the d-c control amplifier. The remainder of the drive is a conventional amplidyne drive.

VELOCITY CHANNEL

When the radar locks on target, it actuates relays which shift the radar, the computer, and the director drives into the track mode. The designation signal is disconnected from the summation unit in the director drive. In the computer, a velocity signal is derived from target displacement data received from the radar. This velocity signal is substituted in

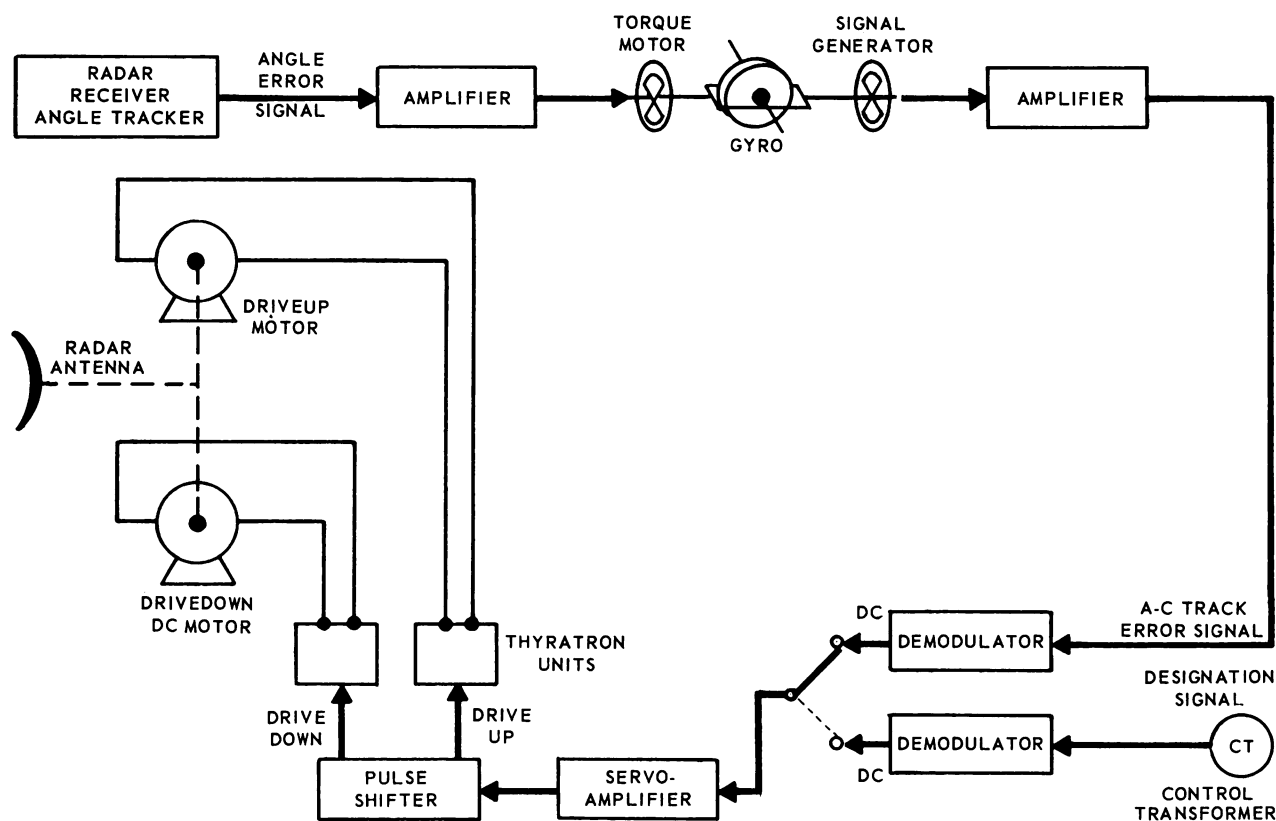
the computer for the search velocity signal. Tracking modifiers are added in the computer to the tracking velocity signal. The computer's part in this type drive is discussed in chapter 3. The tracking velocity signal is sent to the director to drive it at the computed tracking rate. The velocity signal enters the drive at the summation network, and its path through the remainder of the drive's units is the same as that of the designation signal. The director drives the radar antenna to null the displacement error.

Let's consider the gyro unit in the drive. As you know from our discussion of gyros, it has a dual function. It stabilizes the LOS and furnishes the drive with velocity response or feedback. A study of the drive's closed loop will tell us why the velocity response from the gyro is needed. The order signal is derived in the computer from a linear displacement error detected by the radar. The computer derives a velocity signal from the displacement signal. The velocity signal is sent to the director to drive it at the computed tracking rate. Note that there is no feedback between the director drive and the computer's velocity signal mechanisms except through the radar's LOS. Consequently an error in the tracking rate must go through the complete loop to be resolved. This tends to make the system unstable. But with the gyro furnishing a velocity response signal in opposition to the ordered velocity the input to the drive's amplifier is the ordered change in velocity, or an acceleration signal. This arrangement allows the drive to use high gain amplifiers, which results in improved dynamic reaction to an error signal.

RATE-INTEGRATING GYRO DIRECTOR DRIVE

This director drive is a departure from the conventional amplidyne drive. The radar antenna has three axes of motion and three drives are installed: elevation, train, and traverse. These drives have a few unique arrangements. We will discuss the elevation drive first and then the traverse and train drives, which are somewhat more complex.

The elevation drive is broken down into functional blocks in figure 5-11. This illustration is simplified; feedback circuits and limiting circuits are not shown. There are two drive motors, both coupled to the antenna's



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Figure 5-11.—Simplified diagram of rate-integrating gyro drive.

elevation gear. One motor is a drive-up motor (elevate); the other is a drive-down motor (depress). These motors are connected electrically in opposition. This arrangement reduces backlash in the drive's gearing. The drive has a designation channel and a track channel. Relay operation selects the signal source of the drive's servoamplifier from either the designation or the track demodulator. We will follow a signal through the track channel; conventional units and arrangements will not be covered. Designated elevation signals are handled in an identical manner as the track signals; consequently they will not be discussed.

ELEVATION TRACK CHANNEL

The radar is locked on target and the system is tracking. Target displacement errors are detected by the radar. (Incidentally, a monopulse radar is used with this system. The method of error detection in the radar's microwave system is covered in chapter 10.) The output of the

radar to the director's elevation drive is an a-c error voltage proportional to target displacement in the vertical plane. This voltage is amplified and then applied to the gyro's torque motor. The motor precesses the gyro, and the output of the gyro's signal generator is directly proportional to the displacement error. The gyro's functions in the drive were explained when we discussed the integrating gyro.

The a-c signal from the gyro's signal generator is amplified and then rectified in the phase sensitive demodulator. The amplifier and the demodulator are conventional. The d-c error signal, which is proportional to the required movement of the radar antenna, is the input to the drive's servoamplifier. (The selection between the designation signal and the track signal is made at this point.) The polarity of the signal indicates the direction of the required motion. The outputs of the servoamplifier are two d-c voltages. The amplifier has a cathode follower input stage, a signal amplifier stage, a phase inverter stage and an

output stage of two cathode followers arranged in push-pull. Hence the two d-c voltages from the cathode followers swing in opposite directions when there is an input error signal. The swings of these voltages represent a drive-up and a drive-down signal to the pulse shifter unit.

The pulse shifter consists of two sets of tubes with three twin triodes in each set. One set of tubes is for the drive-up signal and the other for the drive-down signal. The pulse shifter's outputs are two sets of trigger pulses. Their occurrence in time with respect to an a-c reference voltage is dependent upon the positive or negative d-c signal from the servoamplifier. Since the drive-up and drive-down circuits are identical, only the drive-down is described.

The drive-down signal from the servoamplifier is applied directly to the grids of the three tubes in the drive-down circuit. The cathodes of the tubes are connected to a three-phase transformer. Each cathode is connected to a separate phase of the transformer's secondary winding. The primary of the transformer is energized by a three-phase reference voltage. The phase relationship between the a-c voltages on the cathodes is 120 degrees. Assume that the tube's grids receive from the servoamplifier an error signal of minus 15 volts. The tubes will conduct when their cathode voltages are more negative than minus 15 volts. This will occur for each tube 120° apart with respect to the a-c reference voltage. The outputs of the tubes are clipped sine waves because the high cathode voltages cause tube saturation. The outputs are fed into three identical differentiating circuits to obtain sharp rising pulses. The outputs of the differentiating circuits are applied to three amplifier tubes which are operated at zero bias and therefore clip the positive going input pulses. The outputs of the pulse shifter's drive-down circuit are taken from the plates of the three amplifier tubes. These outputs are three positive going pulses 120 degrees apart and variable, in time, with the magnitude of the d-c error voltage from the servoamplifier. When the d-c error voltage input becomes less negative, or becomes positive, the triggers to the thyatron tubes are advanced in time with respect to the a-c reference voltage.

The three trigger pulses are applied to three thyatron tubes in the thyatron unit. The plates of these tubes are supplied by a three-phase transformer whose primary is energized by the a-c reference voltage. Each plate is connected to a separate phase; thus

the plate supplies are 120 degrees apart. The thyatron trigger pulses from the pulse shifter unit are applied to the tube's grids. There is a time relationship between the plate supply and the triggers to the grids. Both are measured with respect to the a-c reference voltage. The thyatrons are biased so that with no signal on the grids the tubes will fire near the end of the plate's positive swing. A positive trigger pulse to the grid will advance the firing time and thus lengthen the conducting period, while a negative pulse will delay the firing time and thus shorten the conducting period. You realize, of course, that once the thyatron fires, the tube will continue to conduct as long as the plate is positive.

Since the servoamplifier's outputs are in push-pull, the triggers for one channel are retarded. Positive trigger pulses to the drive-down thyatrons cause the current output to their associated motor to increase. If the trigger pulses to the drive-down channel are positive the trigger pulses to the drive-up channel must be negative. Negative pulses reduce the amount of current from this channel to the drive-up motor. Obviously the torque output of the drive-down motor will overcome the torque of the drive-up motor and the antenna will depress.

TRAVERSE DRIVE

When the radar is tracking an elevated target, the motion of the target across the LOS is in the traverse plane. The antenna's traverse drive follows this motion about the traverse axis. The movement of the director about the traverse axis is limited to a relatively small arc. Therefore, the train drive is interconnected with the traverse. It is difficult to cover either drive without first describing the interrelationship between the two.

In the designation and search modes of operation the traverse drive is driven to its neutral position (centered and on zero). A CT with a fixed rotor furnishes the zero signal. The designation signals are inputs to the train drive. These signals are measured in the deck plane, as is the drive's movement. In the track and acquisition modes of operation the circuit from the CT is disconnected from the traverse drive and is connected to the train drive. Order signals are received by the traverse drive from the radar's angle tracker unit. These signals cause the drive to move the

antenna from its zero traverse position. When the traverse drive leaves its zero position the CT feeds a signal to the train drive which causes it to move in a direction to null the CT signal. Hence the train drive is slaved to the traverse drive which in effect pulls the train drive along as it moves.

The interconnection between the traverse and train drives ensure the capability of the director to track targets with very high bearing rates. The rate is divided between the two drives. The traverse drive passes the bearing rate on to the train drive. If the train drive becomes overloaded, due to a high bearing rate and the inertia of the director, the traverse drive accepts the percentage of the rate causing the overload.

The units in the traverse drive are functionally identical to their counterpart in the elevation drive. Consequently we will not trace a signal through the drive, but simply point out variations between the two drives. In track, the order signal representing target displacement is in the traverse plane and not in the vertical plane. The signal is applied to the gyro and follows a path which is similar to the elevation order signal in its drive. There are four drive motors in the traverse drive, two drive-right and two drive-left motors. In the designation mode the order signal's path is similar to the path the designation signal follows in the elevation drive. The exception here is that the order signal in the traverse

drive is from a fixed CT which drives traverse to its zero position.

TRAIN DRIVE

The train drive is an electric-hydraulic drive. The hydraulic components are not covered in this course since hydraulics are not a qualification for the FT rate. But FTs assigned to directors or antenna positioning systems which use hydraulic devices should familiarize themselves with hydraulic principles and the operation of the devices. This information can be found in *Basic Hydraulics*, NavPers 16193. The GM ratings are familiar with hydraulics, and are a source of detailed information.

In the acquisition and track modes, train is controlled by the clamped rotor CT. Figure 5-12 is a simplified block diagram of the signal's path in the drive; feedback voltages are not shown. The error signal causes the drive to move in such a direction that the train movement will follow the traverse movement. During the track mode, a cross-feed signal from the traverse gyro is added to the CT's input to eliminate any train-traverse oscillations. The traverse order signal input is referenced to the traverse plane, and the train drive moves in the deck plane. Hence the order signal must be modified. The order signal is applied to a secant multiplier stage. This stage consists of two tubes operated as high gain amplifiers. A negative feedback voltage,

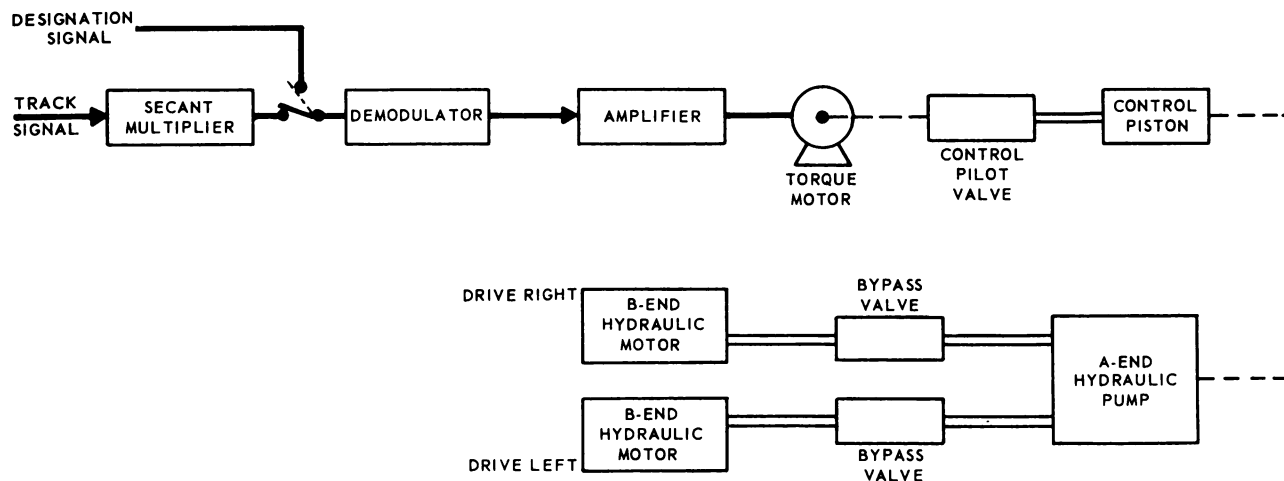


Figure 5-12.—Simplified train drive.

which is proportional to the cosine function of the elevation angle, is applied to the tubes. The gain of the tubes is so high that the overall gain of the stage is determined by the feedback. Therefore, the gain of the stage varies inversely as the cosine of the elevation angle, or as the secant of elevation. This arrangement provides the necessary increase in gain to the train drive for large elevation angles.

The output of the secant multiplier is the input to a phase-sensitive demodulator. The d-c output of the demodulator is in turn the input to the servoamplifier. The output of this amplifier drives the control torque motor in the train hydraulic drive. The torque motor mechanically positions a control pilot valve (fig. 5-12). The control pilot valve hydraulically

controls the position of the control piston. The latter mechanically varies the tilt of the A-end hydraulic pump. The pump furnishes high pressure to two B-end and hydraulic motors. These are drive-right and drive-left motors connected in opposition. The direction of the A-end tilt determines to which motor the high pressure will flow.

In the designation and search modes, the director synchros compare the ordered position with the actual position and produce an error signal. The error signal is applied directly to the demodulator (fig. 5-12). Since the error signal is measured in the deck plane, the secant multiplier stage of the amplifier is not necessary. The signal's path through the drive is similar to the path of the track signal.

CHAPTER 6

BATTERY ALIGNMENT

Battery alignment is a critical factor in the fighting effectiveness of any combat ship with guns or missile launchers. Without proper battery alignment, projectiles and missiles will not hit their targets—regardless of crew efficiency, high power radar and optical equipment, speedy fire control computations, or high rate of fire. Maintenance of accurate battery alignment is a primary responsibility of the Fire Control Technician; but it requires close cooperation with the other weapons department personnel.

The purpose of battery alignment is to adjust the guns of the battery and associated fire control equipment so that the lines of sight of the director telescopes and gun sights, the beam axes of the radar antennas, and the bore axes of the guns in the battery are all parallel when:

1. Dials are matched with correct follow-the-pointer indications.
2. No parallax corrections are introduced.
3. No ballistic corrections are introduced.

In a correctly aligned system, all associated gun bores, etc., remain parallel under these conditions throughout all operating motions, and all instruments, dials, and automatic control equipments measure these motions correctly with respect to the proper reference.

To accomplish this, all these elements must be aligned to a common system of reference points, lines, and planes. Battery alignment can therefore be defined as the process of adjusting all the elements of a weapons system (in a gun battery this includes the director, sights, radars, computer and stable element if any, and the gun mount sights and gun barrels) to these common reference points, lines, and planes, and maintaining them in this relationship.

The battery of a ship is aligned in two distinct steps: original alignment and alignment afloat. Original alignment is the initial alignment made in a fire control and weapons system at the time of original construction and installation. This is a very elaborate and highly

accurate series of operations, done in drydock by the shipbuilder or outfitting yard. Original alignment is also performed whenever a new or modified major weapons system is installed. A check of this alignment is made whenever the ship is in drydock for repairs.

Alignment afloat refers to alignment operations performed while the ship is waterborne (in port or underway). Alignment afloat requires standards of accuracy just as high as those of original alignment. The main difference is that alignment afloat must be performed by the weapons department personnel, with equipment available on the ship.

TRAIN ALIGNMENT IN DRYDOCK

The purpose of train alignment performed in drydock is to set all of the elements so that their train angles are measured from a reference line approximately parallel to the ship's centerline.

The train alignment procedure consists of the following steps:

1. Establish an offset centerline approximately parallel to the ship's centerline.
2. Determine the center of rotation of each element.
3. Train the elements so that their pointing lines are parallel to the offset centerline.
4. Set train dials and synchros to zero.
5. Provide bench and tram marks.

Although these steps are performed by shipyard personnel, the Fire Control Technician should know how they are done and be ready to help, or to check the alignment when called upon to do so. The description of drydock battery alignment operations is presented briefly here. You can find complete details in OP 762 (second revision).

PRELIMINARY CHECKS

Before the train and elevation alignment of an ordnance installation is started, each element in the system should be aligned within itself, and the synchro transmission system should be checked to ensure that it is functioning properly. Check to see that all of the train and elevation synchros are at electrical zero when their dials read zero, and see that the synchro receivers receive the proper values of transmission. In other words, "hold a good transmission check."

OFFSET CENTERLINE

The first step in actual alignment in train is to establish a centerline from which to measure horizontal angles. Usually, because of interference of the ship's superstructure, this line will be an "offset centerline" ashore, parallel to the real centerline of the ship. This centerline is established by use of surveyor's transits.

CENTER OF ROTATION

The next step is to establish the center of rotation of each trainable element (such as gun mounts and directors), so that a transit may be set up to measure the true angle of train of the element. After it has been plotted, the center of rotation must be checked when the element is trained. When verified, the center of rotation is permanently engraved so that it can be used in future checks.

ZERO TRAIN

It is now necessary to establish Zero Train. That is, to set the train dials of each element so that when the dials read zero train, the line of sight or axis of bore of each element is parallel to the centerline of the ship and pointing forward. On after elements the dials are set at 180 degrees, with elements pointing aft and parallel to the centerline.

TRAM AND BENCHMARKS

With zero train established and the dials set, permanent reference marks must be established. A benchmark and a benchmark reading for each director, and a tram block and tram reading for each mount or turret, are established. At any future time when it is necessary to verify dial

accuracy, each element can be trained onto its reference (benchmark or tram) and the dial readings checked.

ELEVATION ALIGNMENT IN DRYDOCK

After battery alignment in train, comes alignment in elevation. The purpose of alignment in elevation is to adjust the battery so that at any angle of train, and at any angle of elevation, the lines of sight of the directors, gunsights, and the axes of the bores of guns, will all be elevated by exactly the same angle above a common reference plane. (Again we assume no vertical parallax or ballistic correction, and we assume that the dials are matched.)

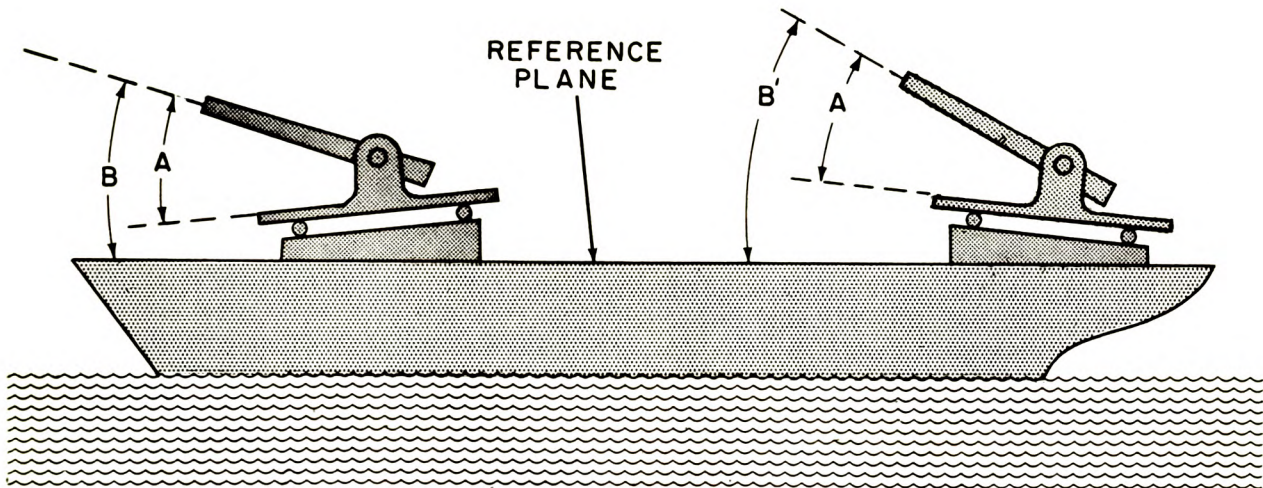
REFERENCE PLANE

The reference plane is an arbitrarily selected plane, approximately parallel to the deck. The train roller paths of all the elements are made parallel to the reference plane, to ensure that they are parallel to each other. The reference plane may be the actual roller path plane of one of the elements; the selection is governed solely by convenience. It may be a leveling plate set well down in the hull, where hull distortion is at a minimum; or it may be an imaginary plane. On cruisers, the reference plane is usually the forward main battery director. On destroyers it is the Mk 37 director. What is the reference plane on your ship?

ROLLER PATH DATA

Figure 6-1 shows the effect on elevation (exaggerated for clarity) of uncorrected tilt or inclination of the roller path. Each of the two gun mounts in the figure is elevated to the same angle (A) with respect to its roller path, but their angles (B and B') with respect to any common reference are not the same.

The principal operation in elevation alignment in drydock is the procurement and interpretation of roller path data. Roller path data are actually a series of readings showing the inclination of the trainable element, relative to some fixed plane, at points all around the roller path. In drydock this is usually a horizontal plane established by a Gunner's quadrant. The relationship between any roller path and the horizontal is defined by the amount of tilt at



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Figure 6-1.—Effect of roller path inclination on elevation.

the highest point of the path, and the relative bearing of this point. Figure 6-2 shows this diagrammatically.

Roller path inclination is measured at regular angular intervals through the full arc of train of the mount or director, and the resulting data are plotted on graph paper. The general procedure for plotting and interpretation of the data is similar to that for the afloat system alignment, which we will describe later in this chapter.

ROLLER PATH COMPENSATORS

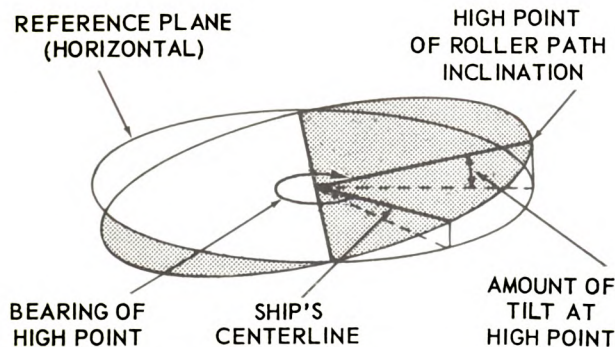
In gun mounts, turrets, and some directors, compensators correct for roller path tilt by adding a compensating tilt algebraically, depending on mount train angle. The amount of

correction at each point in train is equal to the amount of tilt, but opposite in direction. In some elements (such as stable elements, stable verticals, and manually operated directors) no roller path compensators are installed. The base of these elements must be shimmed to correct for roller path inclination.

ZERO ELEVATION

To complete the alignment of the installation, zero elevation positions of all the elements' pointing lines must be made parallel to the reference plane, and therefore parallel to each other.

The zero elevation position of the elements becomes parallel to the reference plane when the roller path tilt correctors are set in accordance with the roller path tilt data previously measured, or when the bases of the elements have been shimmed. The zero elevation position is recorded for use in subsequent realignment by using bench and tram marks. These are established in the same way as for zero train.



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Figure 6-2.—Relationship between roller path and horizontal.

BATTERY ALIGNMENT AFLOAT

Battery alignment afloat is necessary because the ship's hull is a flexible structure subject to small but significant changes in shape induced by the varying forces between drydock and afloat conditions. These changes in hull shape can cause appreciable changes in the alignment of the ship's ordnance, particularly

on long, narrow ships of relatively light construction. For this reason, alignment work done in drydock is only a preliminary step to obtain the best possible approximation of the alignment required when the ship is afloat. Starting with this approximate alignment, the work required to produce the final afloat alignment can be performed with greater ease and accuracy than would be possible if the drydock work has not been done at all. In this chapter we will show the methods used in afloat alignment. Alignment procedures for individual types of ships can be found in OP 2456 (Volumes 1 thru 8).

PRELIMINARY CHECKS

As with battery alignment in drydock, before alignment afloat begins we must ensure that each element is aligned within itself, that all synchros are properly electrically zeroed, and that transmission is accurate. Again, a good and complete "transmission check" is required.

Parallax transmission must also be checked, for it can cause errors that will affect the alignment of an installation. Therefore, before alignment is started, careful checks should be conducted to ensure that the parallax units are computing proper values, and that these values are being applied in the proper direction.

TRAIN ALIGNMENT AFLOAT

The main purpose of the train alignment performed while the ship is afloat is to set all the elements so that their train angles are measured from a reference line approximately parallel to the ship's centerline. When the elements are positioned in train with their pointing lines parallel to the ship's centerline, and train parallax is set to zero, the train dials of the elements will read zero and the train synchros will be at electrical zero. This has exactly the same purpose as train alignment in drydock.

In drydock, the train alignment was performed by establishing an offset centerline. When the ship is afloat this method cannot be used because the constant rolling and pitching motion of the ship, even in very calm water, makes it impossible to use a reference line on the shore or instruments mounted on the shore. Therefore, it is necessary to depend on the benchmarks or tram readings established for the reference director when the ship was in drydock. Hull distortion, or distortion of the

reference director, may cause the zero train position established by these readings to shift slightly, so that it is not exactly parallel to the lines originally established. However, this shift is small and benchmark or tram readings can be depended upon to give satisfactory alignment until readings can be rechecked when the ship is again in drydock.

The reference director is checked on the benchmark or checked with a tram to be sure that the zero train position of this director is parallel to the line originally established in drydock. Before proceeding with the check, it should be determined that the parallax corrector and crosslevel gear (if provided) are set to zero. The director is trained until its telescope is accurately on the benchmark, or until its tram marks or blocks are aligned. The train dial reading of the director is compared to the recorded value. If there is a difference of more than ± 5 minutes of arc, the dials are set to read the correct value. Then the director is trained until the dials read zero and the train synchros are checked to see that they are at electrical zero.

METHODS OF AFLOAT ALIGNMENT IN TRAIN

Two methods are commonly used in the fleet to align a battery in train. One is the "Target at Known Range" method, and the other is the "Target at Infinity" method. The two procedures are exactly the same except that in the "Target at Known Range" method parallax is computed and applied in the normal way to the element to be aligned. In the "Target at Infinity" method parallax is set to zero. In this chapter we will discuss only the procedure for a target at infinity.

Target At Infinity Method

After all the preliminary checks have been made, including the benchmark check, it is possible to proceed with the actual alignment of the various battery elements. Preferably, this should be done with the ship at anchor in smooth water. If the battery has never been aligned, a complete train check is necessary; otherwise a preliminary test may be made to determine if a complete check is necessary. The preliminary test is conducted as follows:

1. Establish telephone communication between directors and guns.

2. Set switchboard for normal operation; i.e., director to plotting room, which in turn transmits to guns.

3. At the computer or rangekeeper, have time motor OFF, power switch ON.

4. Set Vs (sight angle) on 2000 minutes and Ds (sight deflection) on 500 mils (their zero values) on their respective computer counters.

5. Set and lock Level and Crosslevel at ZERO.

6. Set Parallax to ZERO.

7. At the gun, set zero values of Vs and Ds if the gun telescope is to be used. If the boresight telescope is to be used, this is not necessary. Errors can be held to a minimum if the boresight telescope is used.

8. Select a target at infinite range. Either the sun or the moon makes a good target. They should be below 30 degrees elevation. If you use the sun, be sure the proper filters are in place on the telescope.

9. The following information should be relayed to the gun to be aligned: target bearing, target elevation, description of target, and which edge of the target is to be used for alignment.

10. At the gun, match pointers and shift to MANUAL control.

11. Train the director to keep the selected edge of the target matched with the vertical crosshair of the reference telescope.

12. At the gun, the man on the boresight telescope coaches the trainer to bring the center of the reticle within a few minutes of the selected edge of the target in such a direction that the relative motion of the target will cause the selected edge to drift across the center of the reticle.

13. When the selected edge of the target drifts across the center of the reticle of the boresight telescope, the operator calls "MARK".

14. When both the director and the gun are "Marking" on the target at the same time, the train readings of both the director and the mount are recorded.

15. This procedure is repeated as many times as necessary to obtain complete data. From these readings one average director train value and one average mount train value are obtained. Subtract the average mount train value from the average director train value to obtain the mount train dial error.

16. Obtain a number of readings by training from the opposite direction, using the same procedure as above, to obtain a second mount train dial error.

17. Add the two mount train dial errors and divide by 2. The resulting average value is the actual mount train dial error.

18. If the average error does not exceed 2 minutes of arc, the present alignment is satisfactory. If the dial error exceeds 2 minutes of arc, the dials must be corrected.

19. Repeat the process, using a target on the other side of the ship if practicable; in any case, use a target at a widely different train angle from the first. Record the mount train dial error.

20. Compare the errors obtained for the two targets. If the errors are equal, or nearly so, they probably represent a constant error which can be eliminated by adjusting the train response at the gun.

If the errors are not equal, the difference is due to some irregular error which can be evaluated only by performing a complete train check.

NOTE: Unless it is known definitely that appreciable irregular errors do not exist in the installation, it is NOT advisable to make an adjustment to the train alignment on the basis of a 2-target check. When an irregular error does exist, this check should be used only as a periodic test to keep informed about the general condition of the alignment.

COMPLETE TRAIN CHECK

The purpose of the complete train check is to take into consideration the effect of train errors due to roller path inclination and imperfections in the mechanisms of the elements. These errors vary with train, and may change from positive to negative. By sighting on targets at a number of bearings, the errors are determined in a manner which makes it possible to split the variations so that the effect of the errors is minimized. Normally a complete train check is made on initial installation, and the errors reduced to a minimum at that time. Ship's force should check the complete train periodically to determine whether or not a significant irregular error is developing.

ELEVATION ALIGNMENT AFLOAT

After train alignment has been completed, we then align the battery in elevation.

The main purpose of elevation alignment afloat is to set all the elements so that their elevation angles are measured from a plane parallel to the reference plane. When the elements are positioned in elevation so that their

pointing lines are parallel to the reference plane and parallax is set to zero, the elevation dials of the elements will read zero and the elevation synchros will be at electrical zero. As you can see, this operation has the same purpose as elevation alignment in drydock. But the procedures used in drydock cannot be used when the ship is afloat because the constant rolling and pitching of the ship, even in calm water, makes it impossible to use the horizontal plane as a reference. Therefore, as in train, it is necessary to depend on the benchmark reading established for the reference element when the ship was in drydock, and to take roller path data by a different method.

As with train, the reference element is checked on the benchmark to be sure that the zero elevation position of the element is parallel to the lines originally established in drydock. Vertical parallax and crosslevel are set to zero. The element is then brought on the benchmark with the reference telescope. The elevation dial reading is then compared with the recorded value. If there is a difference of more than ± 5 minutes of arc, the dials are set to read the correct value. Then the element is elevated until the dials read zero, and the elevation synchros are checked to see that they are at electrical zero.

Before we go any further in the elevation alignment, we must check to see that each element is aligned within itself, the synchro transmission system is transmitting properly, the parallax system is computing the correct quantity, and the values are being applied in the proper direction.

Horizon Check

When the zero elevation position of the reference element has been aligned with the reference plane, the zero elevation positions of the other elements must be made parallel to that of the reference element. This is accomplished by aligning the elevation dials of each element to the elevation dials of the reference element and setting the roller path compensators to the correct values. This data is obtained from the horizon check.

To perform the horizon check the following steps are necessary:

1. Establish telephone communication between the director and the gun to be aligned.
2. Set elevation parallax equipment for zero output.

3. Ensure that the guns and directors are in MANUAL control.

4. Train the director and the first gun to be aligned to the same bearing.

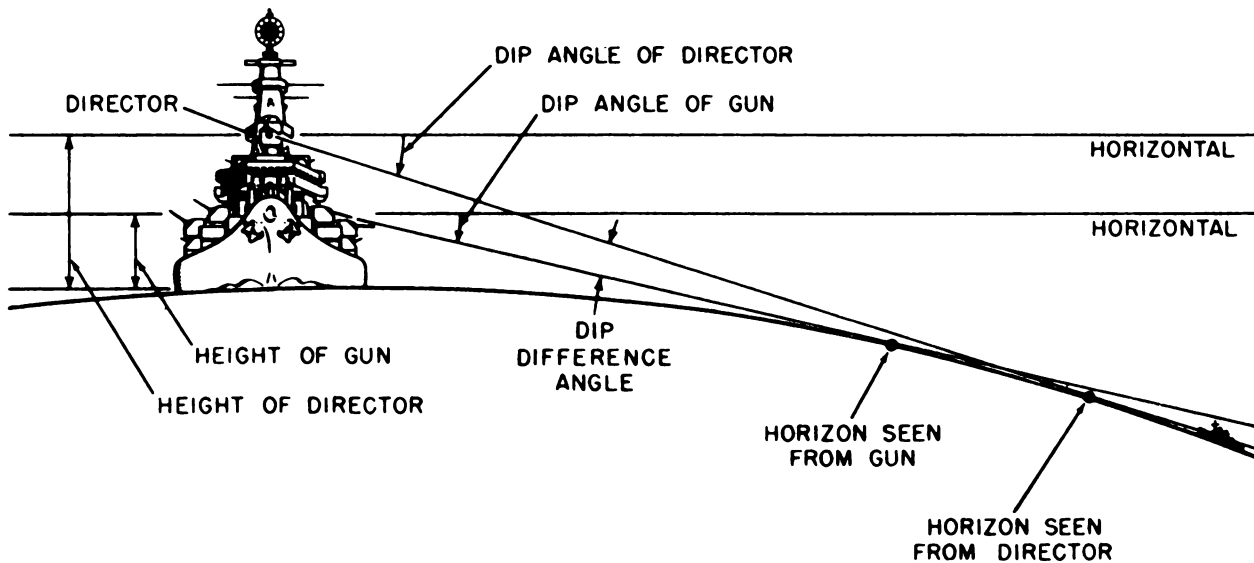
5. Position the director in elevation so that its pointing line swings up and down across the horizon as the ship rolls and pitches.

6. Position the gun in elevation so that its pointing line crosses the horizon at the same instant as that of the director. This is accomplished as follows. At the instant the director operator sees his horizontal crossline cross the horizon, he calls "Mark" over the telephone to the operator at the gun. At the gun the operator notes whether his horizontal crossline is above or below the horizon at this instant. He then adjusts his handwheels to remove the error so that his horizontal crossline will be on the horizon at the instant the director operator calls "Mark." He then calls "Mark" to the director operator to inform him that he is on the target. The readings at both the gun and the director are then recorded and the procedure is begun again at a bearing 15° from the last one. This is continued until the readings have been taken on bearings of 15° for the full arc of train of the mount.

7. Obtain the uncorrected gun elevation error by subtracting the director elevation from the gun reading and record the results for each bearing.

One factor that causes the dial readings to be unequal is the difference in height between the director and the gun. This elevation difference is known as the "dip difference." Figure 6-3 shows the angles which make up dip difference. Dip difference remains constant during the horizon check for one gun, and its magnitude can be determined by figuring the dip angle for both the director and the gun and subtracting the difference. Dip angle for each element can be determined by using the formula $D = 0.98\sqrt{h}$, where D is the dip angle in minutes and h is the height in feet of the element above the waterline. Heights of the various elements can be obtained from the ship's smooth fire control log.

Another factor which causes the dial readings to be unequal is a misalignment between the dials of the director and the dials of the gun. This difference is due only to a misalignment of the elevation dial gearing at the gun, and therefore it is not affected by train, roll, or pitch. Hence this difference also remains constant throughout the horizon check.



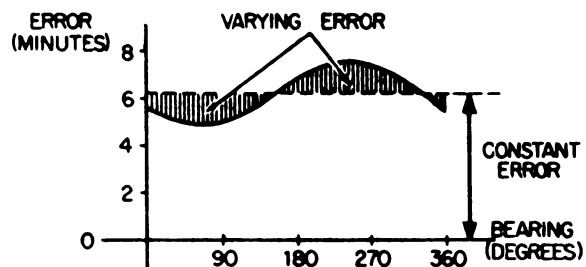
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Figure 6-3. —Dip angle and dip difference.

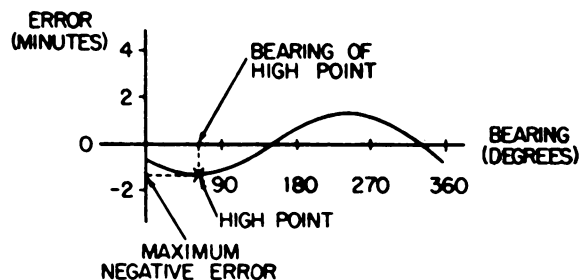
A further difference in the dial readings results when the roller paths of the elements are not in alignment; that is, when the roller path tilt corrector does not have the right settings. Unlike the difference due to dip and dial misalignment, the difference due to roller path misalignment does not remain constant but varies with train angle.

Thus each dial reading difference recorded in the horizon check is the sum of two constant values and a varying value. By the rectangular coordinate method, 60° polar coordinate method, or 180° polar coordinate method (as described in OP 762, chapter 6), the varying factor can be separated from the constant factors to determine the roller path misalignment between the gun and the director. Figure 6-4 shows an example of the type of curve obtained when the horizon data are plotted by the rectangular coordinate method.

After the varying portion of the horizon check data has been analyzed to determine the value necessary for roller path alignment, the constant portion of the data is analyzed to determine the extent of any dial misalignment. Dial misalignment can be determined by subtracting the dip difference angle from the total constant error in the horizon check data. The dials are then adjusted to the proper readings, and the elevation synchros are checked to see that they are at electrical zero when the dials read zero.



A. TOTAL ERROR VS. BEARING.



B. VARYING ERROR VS. BEARING.

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Figure 6-4. —Curve of horizon check data.

Of course the gun will have to be trammed in elevation, and the new tram reading entered in the appropriate logs. This is true for both elevation and train any time the dials are adjusted.

RADAR ANTENNA ALIGNMENT

To align the radar antenna, adjustments must be made in train, elevation, and crosslevel. The elevation axes of the radar antenna must be parallel to the elevation axes of the director's optical equipment (telescopes and rangefinder). This is required so that the radar antenna and the director optical equipment will elevate in planes that are parallel throughout the range of movement. The lines of sight of the director optical equipment and the radar antenna are perpendicular to their elevation axes, and all are moved throughout the same elevation angle so that they remain parallel. If such a condition did not exist, it would be impossible to direct both the radar antenna and the lines of sight onto a target.

In this chapter we will discuss only the physical alignment of the radar antenna. In a later chapter alignment of the radar beams will be covered.

Normally the radar antenna mount is aligned with the optics of the director upon initial installation. This involves locating and shimming of the antenna mount until it is parallel with the optics. This alignment is usually accomplished by the installing yard, and requires the use of special boresighting equipment and tools.

Train and elevation antenna alignment afloat is done by locking on with the radar on a target at least 4000 yards away and checking to see that the vertical crosshair in the trainer's telescope and the horizontal crosshair of the pointer's telescope are on target. If the vertical crosshair of the trainer's telescope is not on target, the radar antenna reflector is adjusted by means of the adjusting bolts until the crosshair is on target. If the horizontal crosshair of the pointer's telescope is not on target, the elevation adjustable coupling of the radar antenna is turned until the crosshair is on target. On many directors there are also adjustments for bringing the antenna on in crosslevel.

OP 2456 (Volumes 1 thru 8) give antenna alignment procedures for each individual type of radar.

GUIDED MISSILE BATTERY ALIGNMENT

Guided missile weapons system alignment for proper operation requires the same degree of accuracy as any conventional gun battery. The mechanics and the complexity of the systems precludes the ship's force from making extensive tests at sea for minor corrections to the initial Navy yard alignment. The initial alignment must be done correctly. This alignment is the direct responsibility of the Navy yard, but as a Fire Control Technician you should be aware of the procedures used and be able to assist and to check the initial alignment when called upon to do so.

DRYDOCK ALIGNMENT

All elements of the guided missile battery are aligned in the same manner as a conventional weapons battery. There is, however, one additional step that must be accomplished before commencing the battery physical alignment. That is the alignment of the radar reference beam and the optical boresight telescope of the radar antenna. This is accomplished by use of a shore tower approximately 100 feet high and at least 1300 feet from the ship, on which is located an optical target and a tunable radar transmitter, as shown in figure 6-5. In some missile systems the radar beam is used as the reference for this alignment. The radar beam is trained and elevated to the tunable transmitter and electrically aligned. The boresight telescope is then adjusted to the optical target and locked in place. In other missile systems the boresight telescope is the reference. The boresight telescope is trained and elevated to the optical target on the tower and then the radar beam is aligned to the tunable transmitter. This is a most critical alignment because in both cases the boresight telescope, after aligning, becomes the only reference line of sight for the director.

After the alignment of the boresight telescope and the radar beam, comes the physical alignment of the director, launcher, and other units of the system.

As with the conventional gun battery, it is necessary to first establish the train zero position of the elements of the system. This is usually done by the "offset centerline method." Then the roller path data is taken on each element, and corrected for the tilt of the individual roller path. Since most of the missile elements do not have roller path compensators or leveling

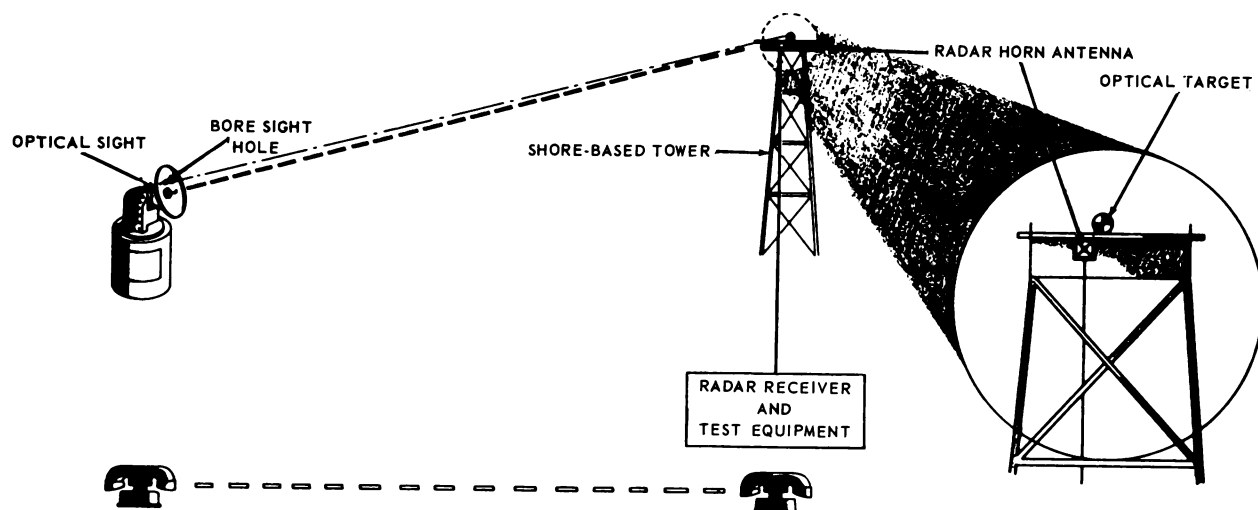


Figure 6-5.—Radar boresight.

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rings, the correction for roller path tilt is accomplished at this time by precise machining of the roller paths until they are within the tolerances specified. Next comes the establishment of the train reference marks (i.e., benchmarks and tram blocks). The positions of these are recorded, and all mechanical dials are set to the proper readings. Zero elevation is then established for each element. The element's position, when aligned to the visual reference marks, is recorded and mechanical dials are set to the proper readings.

At this point the system's mechanical alignment is complete, and means are available to position the elements accurately in train and elevation with respect to the ship's centerline and to their own roller paths, respectively. With all the elements at their train and elevation zero positions, all electrical methods of transmission are adjusted to electrical zero.

PARTIALLY WATERBORNE

The next step in initial alignment is a refinement of the drydock alignment. This is done with the ship partially waterborne. That is, with enough water in the drydock to almost float the ship, but not enough to lift it off the blocks. In this way, the afloat condition is practically duplicated and the blocks prevent any motion. At this time, a recheck and a refinement is made of the train zero, roller path data, benchmarks, elevation zero, and electrical zero of all

methods of transmission. Also, at this time the radar reference beam is again checked, using the shore tower method. If the beam zero indicator (BZI) is out of tolerance with respect to the optical target, look for trouble in the radar. DO NOT move the boresight scope. If no trouble is found in the radar, alignment of the reference beam and the boresight scope must be done again and a complete alignment procedure again carried out. This may be done while the ship is partially waterborne.

AFLOAT ALONGSIDE THE PIER

Generally speaking, the afloat alignment consists of checking all elements on their reference marks (i.e., bench or tram), and taking new roller path data. Again, it is possible that the benchmarks located on the bow or stern may shift slightly. This does not indicate that the system must be realigned. The procedure is to record the new values with the system elements pointing at the benchmarks and use this data for all future checks. The stable element and master gyros will have to be checked against the standard reference roller path for parallelism and, if not within tolerance, shimmed.

This completes the original alignment outline. Complete step-by-step procedures for accomplishing initial alignment may be found in the system OPs and in OP 762 (2nd Revision).

ALIGNMENT AFLOAT (SHIP'S FORCE)

Though we have previously stated that ship's force cannot make extensive tests at sea to correct initial Navy yard alignment, this does not mean that no tests are conducted. There are, as with a conventional gun battery, checks made of the system in both train and elevation to make sure that the angles measured by the missile elements are in agreement with those measured by the reference element. These checks can also give us a good idea of how close the initial Navy yard alignment is within the tolerances prescribed.

Train Check

A check in train is made to determine if the train angle measured by the reference director and the train angle of the missile launcher are in agreement.

Before the train check is begun a good "transmission check" should be made on the system. A boresight telescope should be mounted on the missile launcher rail. All elements should be checked on their benchmarks. Personnel should be stationed at all elements, and telephone communication established. At the reference director, crosslevel should be set to zero.

Select a target at infinite range, preferably a celestial body at a bearing approximately on the beam (090° or 270°) and at an angle of elevation below 30 degrees. Position the reference director on the target, and send positioning data (description, bearing, elevation, etc.) to the launcher. Both director and launcher should be in MANUAL control.

The reference director commences "Marking" while on the target and the launcher "Marks" when it is on. When they "Mark" on target together, train readings are taken at both elements. A series of 10 valid readings should be taken. From these readings one average train reading for the reference director and one average train reading for the launcher are obtained. Subtract the average launcher train reading from the average director train reading to obtain the launcher dial error for that bearing.

The reference director then selects a target as near 180° away from the last target as possible, and the procedure is repeated.

If the launcher dial error is more than 2 minutes, it can be corrected by adjustment at the response shaft in the launcher train receiver regulator, which will adjust the dials. Upon

completion of dial adjustment, position the launcher at 000° train, and check that all synchros are at electrical zero. At this time it is necessary to rezero the load, stow, dud jettison, and transfer position synchros and cams. This will be done in accordance with the system OPs by the GMM assigned to the system.

HORIZON CHECK

As with the conventional gun battery, the purpose of the horizon check of the missile battery is to determine (1) if the elevation angle measured by the reference director and the elevation angle measured by the missile launcher are in agreement, and (2) if the roller path tilt of the launcher is parallel to the reference director (within tolerances). Since most missile system elements do not have roller path tilt correctors or leveling rings, no adjustments can be made to correct for errors in roller path tilt aboard ship. So why do we hold a horizon check? We hold it to ascertain (1) that the element foundations are machined to the reference plane within tolerance (on most missile elements this is ± 3 minutes), (2) changes to initial shipyard alignment due to ship's hull distortion, and (3) the direction and magnitude of roller path tilt error with respect to the reference plane. The horizon check, therefore, has a useful purpose, and the utilization of this check will not only uncover alignment errors but provide a means for maintaining a record of these errors on a continuing basis. When roller path tilt errors are found to be excessive, correction of these errors is accomplished at the naval shipyard by shimming or remachining the element foundation.

As with the train check, before a horizon check is begun a good "transmission check" of the system should be held. A boresight telescope should be mounted on the missile launcher rail. All elements should be checked to their benchmarks. Personnel should be stationed at all elements and telephone communication established. At the reference director, crosslevel should be set to zero.

With the director and launcher in MANUAL control, train to the nearest bearing where both the director and the launcher have an unobstructed view of the horizon. Manually elevate or depress the lines of sight until the horizontal crosswires of both the director telescope and the launcher boresight telescope are on the horizon at the most stable portion of the ship's roll.

The director commences "Marking" each time the horizontal crosswire is on the horizon. The launcher "Marks" when it is on. When both "Mark" on together, readings are taken at the elevation dials of both units, and recorded. The same procedure is repeated every 10 degrees for the full arc of train that will provide a clear view of the horizon.

By plotting the above readings on graph paper by the rectangular coordinate method, 60° polar coordinate method, or 180° polar coordinate method, we can separate the varying roller path tilt error from the constant dial error and the dip difference error. This roller path tilt error should be within the 3 minutes tolerance. If it is not within this tolerance it should be recorded and checked at the next Navy yard availability. After the varying portion of the data is analyzed for roller path tilt error, the constant portion is analyzed for dial error. Dial error may be obtained by subtracting the dip difference from the total constant error. If the resulting error is greater than 3 minutes, the dials are then adjusted at the launcher response shaft in the elevation receiver regulator. The launcher is then trained and elevated to its zero position and all elevation synchros checked for electrical zero. Again it is necessary for the GMM to check and rezero the load, stow, dud jettison, and transfer position synchros.

Upon completion of the train check and the horizon check, the elements of the system are rechecked on their respective branchmarks and new dial readings are recorded in the ship's battery alignment and smooth fire control logs.

Although both of the above tests can and should be conducted by ship's force, it is well to remember that any adjustment to either the train or elevation response requires an adjustment also to the load, stow, dud jettison, and transfer position synchros and cams. These adjustments are extremely critical and difficult to make. So before any adjusting is done to the system by ship's force it would be wise to ask for technical assistance from a repair facility.

FINAL OPERATIONAL CHECK

Modern ordnance installations are operated almost exclusively in automatic control, except under certain special conditions or in emergencies. Therefore, it is particularly important for an installation to be aligned accurately for automatic operation. If the alignment methods

described in this chapter are employed, so that the dials of each element are aligned accurately with the pointing line and the synchros are aligned with the dials, a good alignment should be obtained. However, it is advisable to check the results under conditions which approximate those under which the equipment will be operated.

Perform the check with the installation in automatic control, and with the parallax equipment functioning. If the weapons are equipped with sight telescopes, use them rather than boresights. If a weapon is equipped only with open sights, a boresight telescope will be necessary.

If possible, select various targets at different bearings and at ranges which will be approximately equal to mean battle range for the equipment. For antiaircraft installations, try to use air targets which are at an elevation angle near 45°. The target should produce a slow bearing rate, so that accurate tracking is not difficult.

Train and elevate the director to track a target as accurately as possible, particularly in train. If the director trainer cannot stay on the target continuously, he should inform the operators at the weapons by telephone when he is on, by calling "Mark". The operator at each weapon observes the target through the sight telescope or the boresight, and makes a note of any train error present when the director is on the target. This is done for targets at various bearings, some moving to the right and some moving to the left. In this check, some small error is to be expected because there is always some lag and lost motion in the followup servomechanisms. However, the error observed when tracking to the left should be essentially equal to that observed when tracking to the right, and should be in the opposite direction. If the errors do not change direction when the direction of tracking is changed, or if they are considerably larger for one tracking direction than the other, a misalignment is indicated. This can be corrected by adjusting the train synchros; but before any adjustment is changed, a careful analysis should be made to be certain that the error is not caused by some other factor. For example, a misalignment of the sight telescope could cause an error. This should be corrected by boresighting the telescope—not by adjusting the synchros. In this case, adjusting the synchros would bring the sight telescope on, but would result in firing errors. If, after careful analysis, an adjustment is made to the synchros, a check

should be made to see whether or not a corresponding adjustment must be made to the dials or any other part of the equipment.

MISSILE RADAR ALIGNMENT

Earlier in this chapter we discussed the physical alignment of conventional gun system radars. In those systems we have only one radar beam to align with the director optics. In discussing the alignment of guided missile radar

systems, we talked about the alignment of the reference beam to the boresight telescope. But there is more to guided missile radar beam alignment (collimation) than that. In some of our guided missile radar systems we have as many as four different radar beams—track, capture, guidance, and illumination (fig. 6-6). These must all be collimated to their own zero positions (beam zero indication) and to the reference beam. In some guided missile radar systems the guidance beam is used as the reference

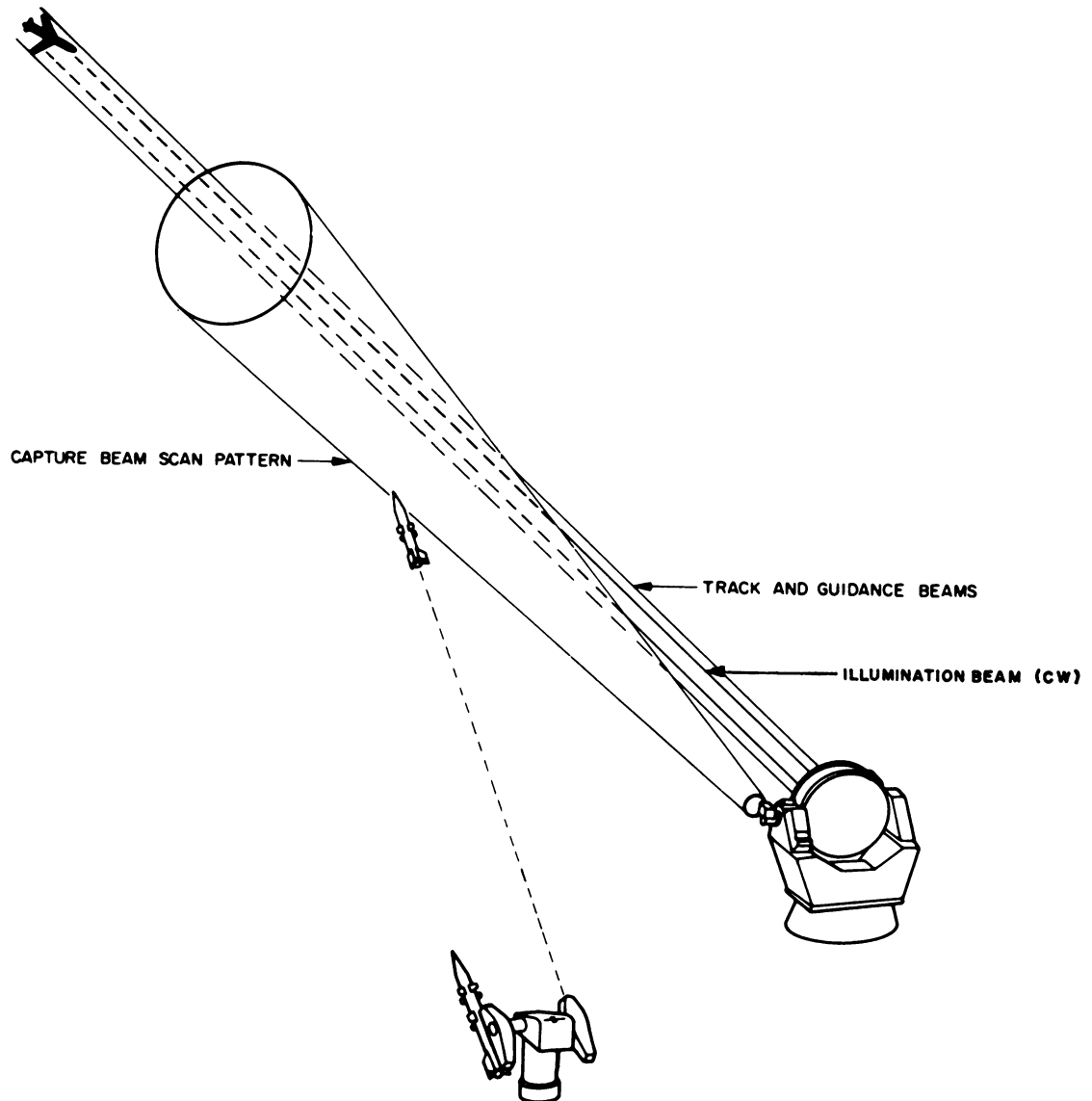


Figure 6-6.—Track, capture, guidance, and illumination beams.

beam, while in others the track beam is used. Whatever beam is used, the problem is the same; all the other beams must be collimated to the reference beam.

Of course collimation of radar beams requires that the radar itself be in top working condition—that is, completely aligned within itself and transmitting at the proper frequencies. Insertion loss measurements must have been made on the C-band microwave components (track, capture and guidance radars) on both the transmitting radar and the shore or ship tower horns. Insertion loss is a combination of mismatch loss (reflective) and attenuation loss (dissipative). To ensure maximum power transfer, insertion losses in the C-band power lines must be measured. Instructions for measuring these losses may be found in the individual system OPs.

COLLIMATION TOWERS

SHORE TOWERS

Shore towers are located at all the principal navy yards in the continental United States, and

at some overseas bases. Each of these towers (fig. 6-7) is equipped with an optical target, a capture antenna, a track and guidance antenna, and an illumination antenna, so arranged as to permit collimation of various types of radars. The tower site has all of the special testing equipment necessary for radar beam collimation. The towers are so located at the navy yards that they may be seen from different piers, allowing ships to collimate their radars without moving to special collimating piers. The tower has communication facilities for direct contact with the ship during collimation. The shore towers are normally manned by special navy yard technicians, but the ships may be called on to furnish some of the personnel.

SHIP TOWERS

All guided missile ships will have bow and/or stern towers installed in accordance with current BuWeps instructions. Each tower will contain an optical boresight target, a capture antenna, and a track and guidance antenna. The

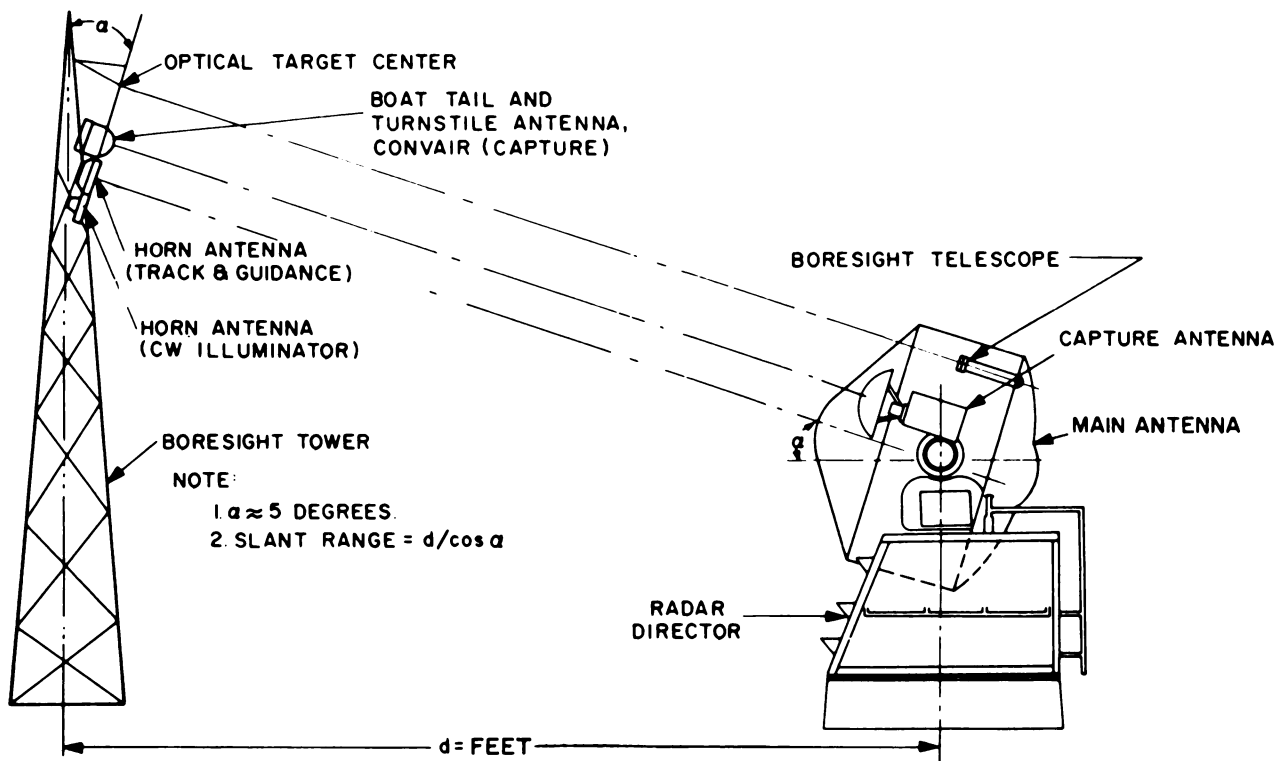


Figure 6-7.—Arrangement of shore-based boresight tower.

ship's tower is intended to provide correlation data at the time of shore tower boresighting and collimation, and to check C-band alignment of the radar set against the correlation data when a shore tower is not available. To obtain correlation data, test readings are first taken using the shore tower; then the radar is trained and elevated to the ship tower and test readings are again taken. After the readings taken at the shore tower are correlated with those taken at the ship tower, we can check the alignment of the radar at sea, or in port when a shore tower is not available, by use of the ship's tower.

COLLIMATION OF RADAR BEAMS

Let's take a look at the collimation of a typical four-beam missile radar system, using the guidance beam as the reference beam. The conical scanning axes of the capture and guidance beams are aligned with respect to the boresight telescope of the main antenna. The electrical axis of the wide-angle capture beam is parallel to the track beam, while the electrical axes of the guidance and illumination beams are coincident with the track beam (fig. 6-6). The nutation of both the capture and guidance beams produces an amplitude modulation effect at the receiver of the beam-rider missile.

The collimation procedures can be divided into two main groups: (1) those performed in port with the aid of a shore tower installation, and (2) those performed in port or at sea with the aid of only a ship tower. The following checks are those required for both shore and ship towers.

GUIDANCE BEAM ZERO INDICATION (BZI)

The optical center of the boresight telescope must be aligned with the electrical center of the guidance (reference) beam to ensure reliable boresighting and collimation results. The object of this procedure is to boresight the guidance beam at the center of the guidance frequency and to check that the boresight telescope crosshairs are coincident with the center of the optical target.

To achieve this objective, the radar is positioned manually to center the boresight telescope on the shore tower optical target. Connect a

radar test set (SPM-9 or equivalent) to receive a signal from the track-guidance horn at the shore tower. With only the guidance transmitter radiating and transmitting at the center guidance, adjust the radar test set to display the guidance pulse on the CRT and reposition the mount until guidance BZI is obtained. Guidance BZI is determined by observing the radar pulse on the radar test set and positioning the antenna until waveform A of figure 6-8 has changed to one with a minimum of modulation B of figure 6-8. Connect a beam zero indicator between the oscilloscope and the shore tower horn. Position the radar antenna manually until minimum amplitude of the 30-cps sine wave observed on the oscilloscope is obtained. The guidance beam is now electrically boresighted at the center guidance frequency.

As you know, most guided missile radars transmit at three different guidance and capture frequencies (low, center, and high) to avoid range ambiguity, blind velocity, and interference from other radars in the near vicinity. Therefore, we must also obtain a BZI for the low and high frequencies.

At center frequency BZI, the crosshairs of the boresight telescope should be at the center of the tower optical target. If the crosshairs are not on target, the telescope is adjusted until they are. The optical axis is now aligned to the center of the guidance beam. The next step is to tune the guidance transmitter to within 3 mc of the high guidance frequency and repeat the same procedure for minimum modulation of the transmitted pulse. Record the position of the boresight coordinate observed on the optical target. Next, tune the guidance transmitter to within 3 mc of the low guidance frequency and repeat the procedure, observing the boresight coordinate on the optical target. Guidance BZI has now been established for the center, low, and high frequencies of the guidance transmitter.

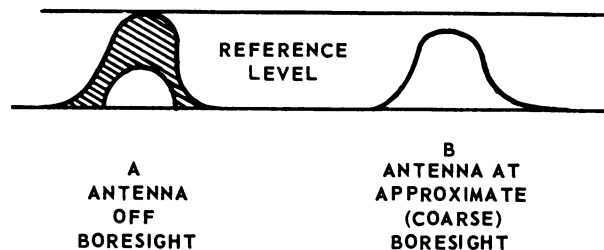


Figure 6-8. —Beam zero indication (BZI)

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GUIDANCE POWER DENSITY AND MODULATION SLOPES

To ensure that the guidance beam is being transmitted within specified power density and modulation slope limits, we must check these values.

If the missile were to receive too much power, its receiver would become saturated and erratic operation of the missile would result. Conversely, if the missile receiver were to receive too little power it would not operate properly, and erratic or no operation of the missile would result. So, power density must be measured to ensure that it is within the specified levels. To measure power density, leave the radar positioned on the center guidance frequency BZI, and measure the guidance signal power level received by the radar test set at the tower. The power level of the guidance signal should be within the limits set forth by the system OP.

Modulation slope measurements are used to determine the amount of power available to the missile receiver when the missile is not exactly in the center of the guidance beam. To determine modulation slopes, we move the antenna a fixed distance (depending on the type of radar) right, left, up, and down from the BZI positions for center, low, and high frequencies, and record the modulation of the received signal indicated on the radar test set. The radar system OPs will have a graph showing the allowable limits of the modulation slopes for each type of radar.

CAPTURE AND GUIDANCE BEAM COLLIMATION

Actually this step could be called Capture BZI, for we are obtaining the BZI for the capture beam using the guidance beam boresight coordinate. In this way we are aligning the electrical center of the capture beam to the electrical center of the guidance beam. Capture BZI is obtained in much the same manner as was described for the guidance BZI, except that instead of using the optical target center as the BZI point of aim we use the Guidance BZI boresight coordinates. The antenna is trained on the center guidance frequency boresight coordinate. The guidance transmitter is turned off, to eliminate guidance beam interference. The capture beam transmitter is energized. At the radar test set on the shore tower, display a capture pulse.

Move the antenna manually until the 30-cps waveform (A of fig. 6-9), breaks into a 60-cps waveform having equal peaks and valleys (B of fig. 6-9). Capture BZI has now been obtained. Observe that the boresight coordinate of the capture BZI is within the value specified on the capture and guidance sheets supplied with the radar set. If the reading is not within specified limits, the capture antenna must be mechanically shifted until it is.

The above procedure is then repeated for the low capture and the high capture frequencies. The electrical centers of the capture and guidance beams are now aligned to each other.

CAPTURE BEAM POWER DENSITY AND MODULATION SLOPES

To ensure that the capture beam is being transmitted within the specified power density and modulation slope limits, we must, as we did with the guidance beam, check these values. If the missile receiver were to receive too much or too little capture power we would have erratic operation of the missile, so we must measure the power density in the same manner as we did with the guidance beam power, and check these values against the established values for the system.

The procedure for checking the capture modulation slopes is the same as that given for the modulation slope measurements of the guidance beam.

Allowable values for both power density and modulation slopes are given in the system OPs.

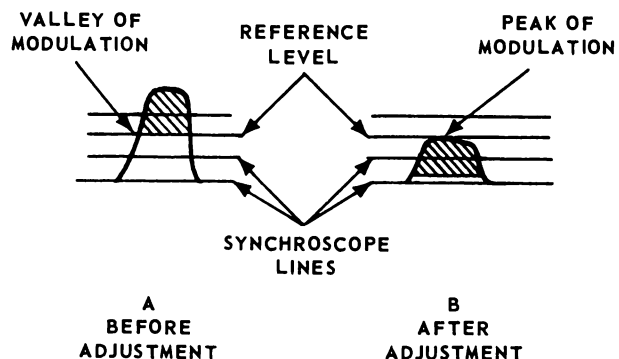


Figure 6-9.—Modulation slopes wave forms.

CAPTURE AND GUIDANCE BEAM AM/FM PHASE ALIGNMENT

From our previous studies we remember that the capture beam radiates from the capture antenna and is conically scanned in space. The conical-scan pattern covers an angle sufficiently wide to ensure capture of the missile, which is in free flight upon leaving the launcher. When

the missile enters the capture beam, it determines its position relative to the centerline of the beam pattern by comparing the phase relation of the amplitude of the received capture pulse groups (AM) with their repetition frequency, which is frequency modulated (FM) in synchronism with the rotation of the capture beam (fig. 6-10). A control system within the missile activates the missile control surfaces

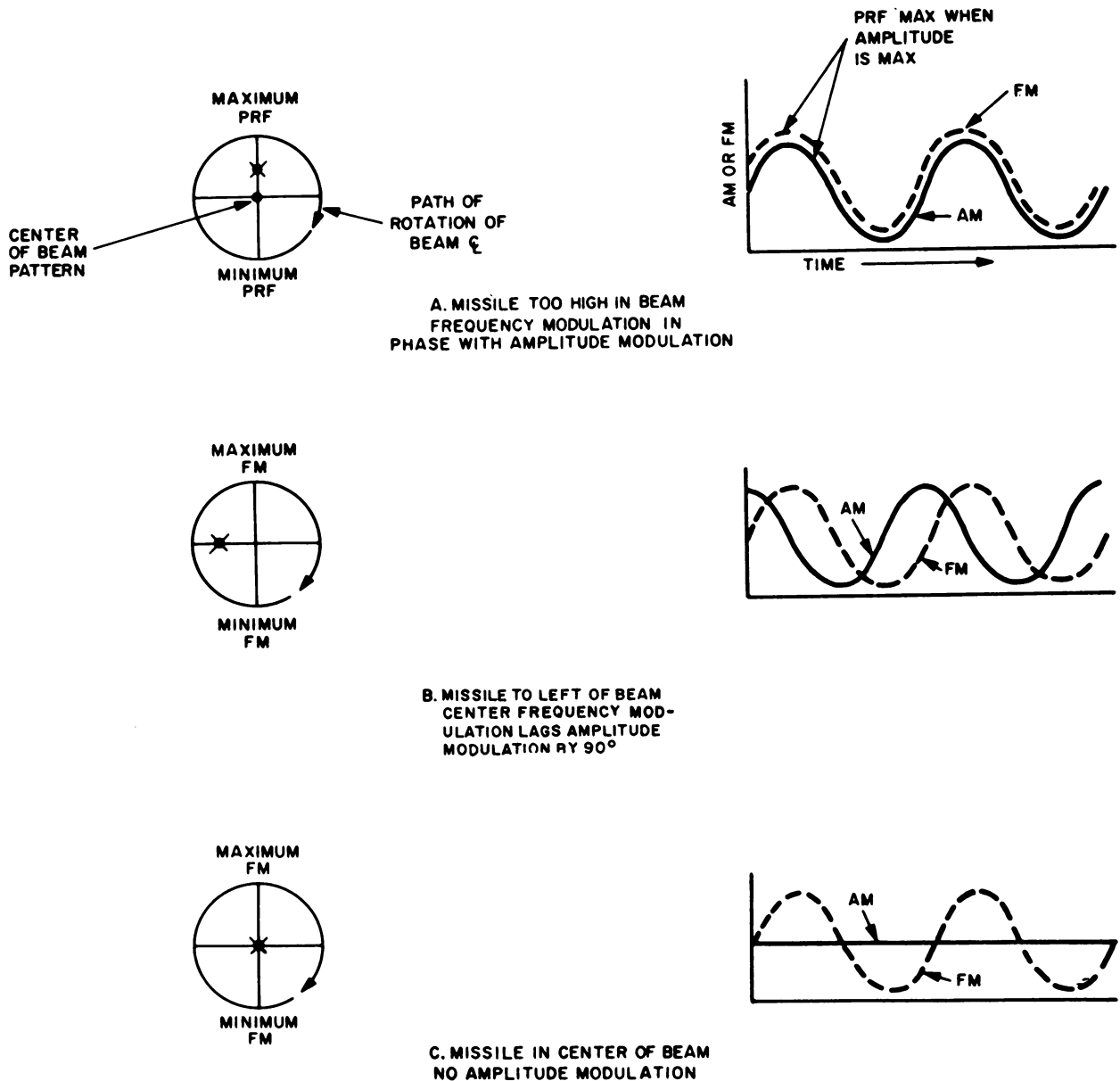


Figure 6-10. —AM/FM phase relationship.

to direct the flight of the missile into and along the centerline of the capture beam.

In the capture and guidance beam collimation check, we made the two beams coincident with each other. Upon reaching the center of the capture and guidance beams, the capture phase is completed. The missile maintains its position relative to the centerline of the guidance beam by sensing the intelligence contained in the beam in essentially the same manner as described for the capture beam. Therefore the AM/FM phasing of both the capture and guidance beams must be checked to ensure that the missile receives the same intelligence when it enters the guidance phase as when it was in the capture phase.

To align the AM/FM phase of the capture beam we tune the capture transmitter to the center capture frequency. Position the main antenna to the center guidance frequency boresight coordinate. Connect a radar test set to the capture antenna at the shore tower. At the test set we will compare the phase of the transmitted capture beam with the test set reference phase. At BZI the reference and the transmitted beam should be in phase. The antenna is then moved up, down, left, and right by an amount prescribed in the system OP and the phase relationship is checked against the system standard given in the OP. If the phase relationship is not within the allowable tolerance, the FM-adjust synchro on the 30-cycle reference oscillator is adjusted to obtain the correct relationship.

The above procedure is repeated for the guidance beam. If the phase relationship of the guidance beam is not within the specified tolerance, the capture-guidance adjust synchro on the angle tracking assembly is adjusted.

TRACK AND GUIDANCE BEAM CONCENTRICITY

To complete our shore tower collimation of the C-band portion of the microwave system we must now check that the electrical centers of the track and guidance beams are concentric. To do this we establish guidance BZI and lock on to a range calibrator pulse generated at the track and guidance horn on the shore tower. In the train and elevation track receiving circuits, voltages are checked and compared with allowable voltages given in the system OP. If the voltages are not within the allowable limits, the track receiver angle sensitivity must be checked.

SHORE TOWER X-BAND COLLIMATION

To complete our use of the shore tower we now measure the power density of the X-band illuminator beam and check the collimation of this beam with respect to the track beam.

To ensure that the target is illuminated with the maximum amount of r-f energy, the beam power density is measured in the manner previously described for the capture and guidance beams.

To illuminate the target properly, the electrical center of the CW illuminator beam, which originates from virtually the same point as the track beam, must be concentric with the track beam within a very small tolerance. To check this tolerance we:

1. Position the main antenna on the optical target at the shore tower.
2. Record the beam power level of the illuminator beam at the tower.
3. Elevate the antenna until the power level is 3 db below that recorded in step #2.
4. Sight through the boresight telescope and record the elevation boresight coordinate.
5. Repeat the above procedure for a decrease in elevation and left- and right-train position of the antenna.
6. Calculate and record the elevation and train boresight coordinates for the center of the CW illuminator beam by algebraically adding the coordinates of elevation and then those of train, and dividing them by two.
7. Check that the boresight coordinates of the illuminator beam are within the allowable limits, as prescribed by the system OP, from the center of the guidance frequency boresight coordinates previously established. If the illuminator beam is not within the allowable limits, it must be realigned by navy yard technicians.

SHIP TOWER BORESIGHTING AND C-BAND COLLIMATION

The ship tower is intended to provide correlation data at the time of shore tower boresighting and collimation, and to check the C-band alignment of the radar set against the correlation data at sea or in port, when a shore tower is not available. The ship tower correlation data should be acquired and recorded, along with the data derived from the shore tower checks, each

time the shore tower boresighting and collimation checks and alignments are performed. Correlation data is comparable to dry dock data in conventional battery alignment.

Because the checks and alignments made at the ship tower are the same as those made at the shore tower, the ship tower procedures may be performed after the shore tower boresighting and C-band collimation are completed. However, if experienced personnel and sufficient equipment are available to man both the shore tower and the ship tower simultaneously, the ship tower procedure may be performed after the corresponding shore tower procedure. In any case, ship tower correlation checks must be made only after the applicable shore tower alignments have been checked.

When using the ship tower to correlate the shore tower data, it must be remembered that readings taken at the bow and stern towers will be within the near zone of the tracking and guidance radar beams. Therefore, measurements of beam widths and guidance slopes will normally be wide and low, respectively. Also, reflections from the deck and launchers may affect indicated capture measurements due to the wide beam widths involved. It is necessary therefore, when taking the correlation data, to record the position of the launchers and to duplicate this position when checking the correlation data.

MISSILE TEST SETS

Although there are many pieces of special test equipment used in the collimation, correlation, and testing of the guided missiles and their radars, the following are the ones which the Fire Control Technician will be interested in during radar/missile correlation aboard ship.

The GUIDED MISSILE TEST SET is a self-contained electronic testing and evaluation device which performs GO/NO-GO tests on the flight and guidance components of the missile. The test set indicates whether or not the missile is flight-ready; if not, it shows the probable fault location within one or more missile packages.

Each test set provides two modes of operation, the Missile Systems Test (MST) and a manual testing mode. The MST comprises an automatic self-test and an automatic programmed test of the missile. The automatic self-test

ensures that the test set is functioning properly. During MST, the test set programs the missile through a sequence of operations which simulate warmup, launch, boost, beam capture, guidance, and missile reset. The responses of the missile are compared automatically with ranges of acceptable values in the test set, and the results are displayed by GO and NO-GO lamps and FAULT lamps on the front panel. These lamps either indicate a satisfactory missile or identify replaceable faulty packages or sections.

Manual testing permits immediate troubleshooting and checkout of defective packages in the missile. The same test signals that would be applied automatically in a missile test sequence are selected individually by appropriate switches. The results are read on a built-in vacuum tube voltmeter.

The RADAR TEST SET consists of three units: (1) a spectrum analyzer, (2) a synchronization indicator, and (3) a single comparator. The test set analyzes the characteristics of r-f signals emitted by the radar and the Guided Missile Test Set to verify correct r-f energy level, modulation, phasing, coding, and pulse characteristics.

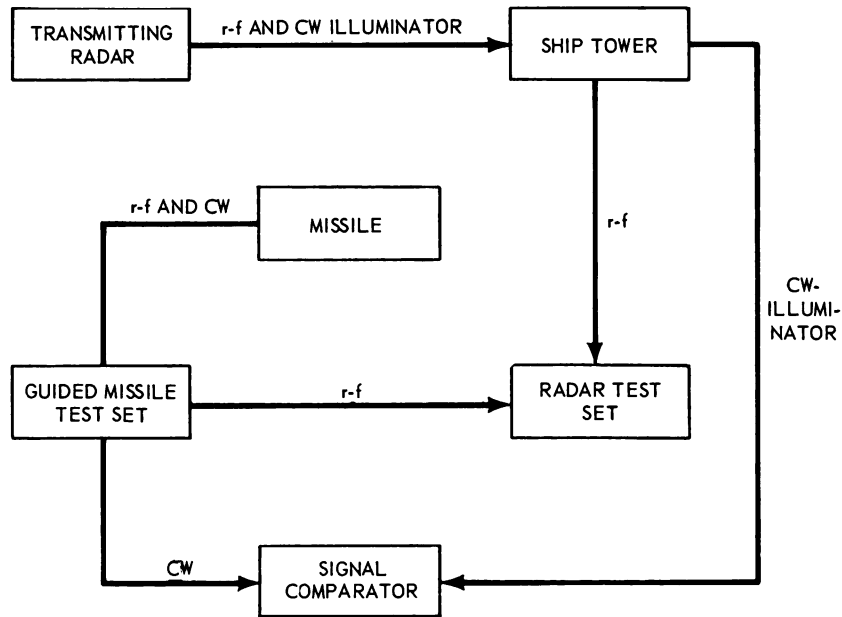
The SIGNAL COMPARATOR tests the frequency and analyzes the characteristics of the signal transmitted from the illuminator radar system and the missile test set. This ensures that the signals are compatible with each other and the requirements of the missile.

RADAR/MISSILE CORRELATION

To determine the flight readiness condition of guided missiles, the guided missile test set must accurately simulate the characteristics of the appropriate tracking and guidance radars. Regardless of the flight readiness condition indicated by the missile test set, the missile must properly respond to signals from the radar in order to achieve target intercept. Thus, without accurate correlation between the radar, missiles, and the missile test equipment, the missile could be tested to an incorrect standard.

The radar test set, as its name implies, is used primarily to check the performance characteristics of the radar, and is so used in the missile radar collimation. It is also utilized, however, to assist in determining radar/missile correlation.

Basically, in a guided missile system there are two modes of operation that must be



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Figure 6-11. —Radar/missile correlation.

correlated—beam riding and homing. In each of these modes, the signals received from the radar are compared with the simulated radar output signals from the guided missile test set (fig. 6-11). Some of the characteristics compared are r-f energy, level, modulation, phasing,

coding, pulse frequency, and pulse width.

Radar/Missile correlation for the homing mode of a missile system using a CW illuminator is achieved by comparing the CW radar output of the guided missile test set with that of the radar set.

CHAPTER 7

SPOTTING AND NAVAL GUNFIRE SUPPORT

SPOTTING

Spotting is the estimate of the correction in range, elevation, and deflection required to hit the target. The spotter observes the fall of shot and estimates the corrections required. Spotting is an integral part of fire control; therefore it is necessary for all fire controlmen to understand it.

Conventional spotting procedures apply principally to surface fire. With modern fire control systems, attempts to spot AA firing usually result in unsatisfactory firing. Normally, no spotting will be done on an air target unless a constant systematic or alignment error is found by observation of fire, and is not immediately capable of correction. No spotting will be permitted during an AA firing run. Spots to correct errors in AA firing will be made between runs.

In the first part of this chapter we will discuss spotting of surface fire only. Later in the chapter we will cover gunfire support spotting and the specialized spotting procedures involved.

DEFINITIONS

SALVO. A salvo consists of one or more shots fired simultaneously by the same battery at the same target.

SLOW FIRE. Slow fire is that type of fire in which the fire is deliberately delayed to allow for the application of spots or to conserve ammunition.

RAPID FIRE. Rapid fire is that type of fire which is not delayed for the purpose of applying corrections.

MEAN POINT OF IMPACT (MPI). The mean point of impact is the geometric center of the points of impact of the various shots of a salvo, excluding wild shots (fig. 7-1).

WILD SHOT. A wild shot is a shot whose dispersion is abnormal in comparison with the dispersion of other shots fired in the same salvo.

PATTERN. The pattern of a salvo is the area covered by the points of impact of the shots (excluding wild shots). The pattern in range is the distance measured parallel to the line of fire between the point of impact closest to the battery and the one farthest away. The pattern in deflection is the distance, measured at right angles to the line of fire, between the point of impact farthest to the right and the one farthest to the left (fig. 7-1).

DISPERSION. The dispersion of a shot is the distance of the point of impact of that shot from the MPI. Dispersion in range is measured along the line of fire and is positive when the shot falls beyond the MPI. Dispersion in deflection is measured at right angles to the line of fire and is positive when the shot falls to the right of the MPI.

HITTING SPACE. The hitting space for a target is the distance between the base of the target and that point beyond the target where a shot passing through the top of the target will strike the horizontal plane through the base of the target (fig. 7-2).

DANGER SPACE. The danger space is the distance, measured along the line of fire and in front of the target, so that if the target were moved toward the firing point, a shot striking the base of the target in its original position would strike the top of the target in its new position (fig. 7-2).

STRADDLE. A straddle in range is obtained from a salvo when, excluding wild shots, a portion of the shots of the salvo fall short of the target and the rest fall beyond the target. A straddle in deflection is obtained when the shots of a salvo fall both to right and left of the target. A straddle may also be obtained when more than

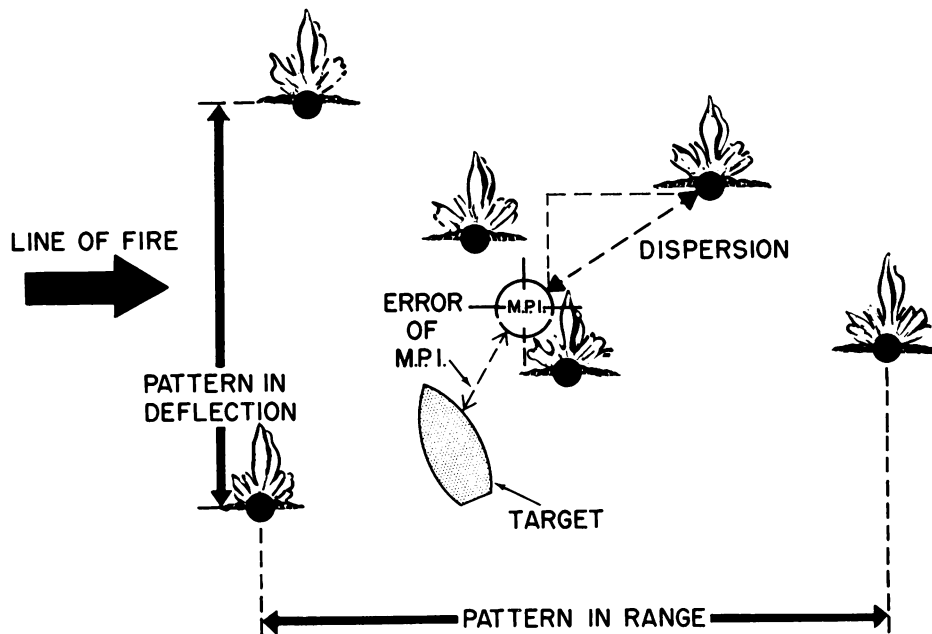


Figure 7-1. —Salvo pattern.

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one salvo is fired, if some salvos fall short and others fall beyond the target.

ERROR OF THE MPI. The error of the MPI is the distance, in range and deflection, of the MPI of a salvo from the center of the target, measured parallel to the line of fire in range and at right angles to the line of fire in deflection.

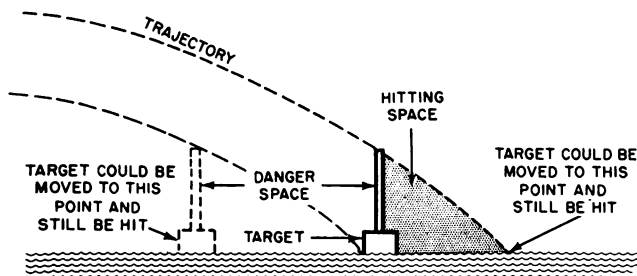
CAUSES OF DISPERSION

Dispersion is caused by errors which are inherent in the firing of guns under operational

conditions. These errors are due to such variations as minor differences in weight and temperature of powder, irregularity in operation of recoil systems, misalignment of guns, etc. Because of these errors, we can always expect some dispersion in the points of fall of the projectiles from several guns fired in a salvo under operating conditions.

DESIRABLE PATTERN SIZE

If the MPI is at the desired point of impact, a pattern of small dispersion can be expected to yield the maximum number of hits. Where excessive errors creep in, however, excessive dispersion results. In such a case the pattern is so spread that few shots are grouped around the desired point of impact; therefore, a minimum number of hits is probable. From the standpoint of a maximum number of hits, it would seem desirable to eliminate errors completely so as to have a zero pattern in range and deflection. Such a pattern would be desirable if the MPI were always at the desired point of impact. It is difficult in actual firing, however, to place the MPI at this desired point. Since it would be better to hit with some of the shots than to miss with all, a larger pattern size would be better.



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Figure 7-2. —Hitting space and danger space in range.

In the Naval Warfare Information Publication, (NWIP) 22-2 there are tables giving the average pattern sizes for the various caliber guns. These tables were constructed from firings conducted at the Naval Weapons Laboratory. Patterns in the fleet should be no larger than those given in the tables.

SHIFTING OF THE MPI

Since dispersion of individual shots is caused by unpredictable errors, it is logical to assume that no two salvos will be exactly alike. Hence, the MPI of the shots of a given salvo can be expected to differ in location from the MPIs of other salvos.

The average shift between successive MPIs is usually so small as to be difficult for the spotter to estimate. Therefore, the spotter should not be too quick to spot when only one or two salvos seems to wander off the target during a string that is, in general, satisfactory.

CONTROL ERRORS

So far, the only errors we have considered are those which are inherent, and which cause errors in individual salvos and dispersion of the MPI. There are also other errors which must be considered. These are called CONTROL ERRORS or CONTROL INACCURACIES.

Before the first salvo is fired, all known effects that would cause an error in the MPI are taken into account. If this salvo or subsequent salvos have an error of the MPI, (disregarding inherent errors), the cause for the error would most likely be one of the following control errors:

1. Incorrect rangekeeper setup.
2. Incorrect ballistic corrections.
3. Battery not properly aligned with the controlling director.
4. Personnel errors. For example, if the director pointer or trainer were not on the target when the salvo was fired. It is unlikely that either of them would be off by a great amount; but if they are, they should notify the spotter immediately so that he may recognize this error and not spot to correct it.

SUMMATION OF ERRORS

During firing, a spotter cannot sit in his station aloft and carefully analyze each fall of shot to determine the exact MPI of a salvo. Splashes are visible for only a few seconds, and

the firing situation is likely to change during even this short interval. The spotter must have previously analyzed all probable errors, such as those we have just covered, and the reason for them. This knowledge, coupled with practical training, will enable him to make instant and intelligent decisions as to the proper spot. The errors attending shipboard firing are:

1. Inherent errors, causing a shift in the MPI of successive salvos. This shift is usually small, but should be corrected if it becomes excessive.
2. Control errors, causing error of the MPI. These errors can be held to a minimum by proper training of the control personnel.

The spotter should be alert to recognize these errors in order to spot correctly.

SPOTTER QUALIFICATIONS

A good spotter should have the following qualifications:

1. An even calm temperament, not excitable under stress.
2. Sound judgment.
3. Decisiveness.
4. Ability to make decisions instantly.
5. Alertness.
6. Normal eyesight, hearing, and speech.

General Functions and Duties of Spotters

Besides his primary function of correcting the fall of shot, there are other functions which the spotter must perform before and during firing. In general these are:

1. Describe the enemy forces (general bearing line, number of ships, deployment, etc).
2. If he is also acting as the control officer, he estimates the values of range, target angle, and target speed, and keeps plot informed of all changes to these values.
3. Keep control informed of the tactical situation.

There are other duties which the spotter may be required to perform. Their exact nature will vary with different types of ships. The spotter's detailed duties and spotting procedures are prescribed in the ship's "Weapons Department Organization Manual," and in fleet doctrinal publications.

Since you are familiar with the methods of estimating the target's course and speed, this

chapter is limited to the spotter's most important function—observation and correction of the error of the MPI by standard methods of spotting.

SPOTTING MPI ERRORS IN DEFLECTION

It is much easier to spot in range if the deflection MPI is in line with the target. Therefore, the MPI should be spotted in deflection first. In deflection spotting, the estimated target width in mils should be used as a guide. Also, spotting glasses, binoculars and stereoscopic rangefinders are fitted with mil scales to furnish means of estimating deflection errors.

In deflection spotting, it should be remembered that it takes a few seconds for the splashes to rise to their maximum height after a salvo. Since the splashes are the spotter's reference, he must allow for target travel while the splashes are forming. Ideally then, the splashes should appear slightly abaft the target's beam. The distance abaft the beam is determined by the caliber of the gun, because larger caliber gun splashes require more time to build up to maximum height.

SPOTTING MPI ERRORS IN RANGE

Spotting in range is more difficult than spotting in deflection. There is no convenient angular measure such as the mils that is uniformly applicable to all ranges. However, with good visibility and a spotting station 100 feet above the water, the error of the MPI can be estimated with reasonable accuracy up to about 15,000 yards. This is done by observing the base of the splashes in relation to the waterline of the target.

Proficiency in range spotting can be gained by actual practice during gunnery exercises or by drill on a spotting board. Spotting boards are so constructed as to simulate actual conditions of splashes relative to the target. Spotting diagrams, such as figure 7-3, are used in conjunction with the spotting board. Figure 7-3 shows schematically how different ranges look to the spotter from a height of 100 feet above the water's surface. The lateral broken lines represent range in increments of 1000 yards; the diagonal broken lines represent angular mils; and the curved solid line at the right shows the apparent length in mils of a 600-ft long target at various ranges. As can be seen, it is more

difficult to spot range errors when the target is at long range than when it is at short range.

METHODS OF SPOTTING

There are three methods of visual spotting: DIRECT, BRACKET or HALVING, and LADDER. Which one we use depends on the type of battery firing, type of target, visibility, and range.

In DIRECT SPOTTING the MPI is spotted directly to the target. This method is good, but is usually limited to short ranges and good visibility conditions.

The BRACKET or HALVING METHOD is usually used in long range firing. The idea behind this method is to spot the splashes until we know for sure that we have crossed the target. The spot is then reversed and cut in half until we have crossed the target in the other direction. We continue this procedure until hits are obtained.

In the LADDER METHOD, fire is deliberately opened short of the target and succeeding salvos are fired so as to approach the target in steps. These steps are usually 200 yards. As soon as the target is crossed the steps are reversed and cut in half until the target is again crossed. After a salvo has straddled the target we may rock the ladder back and forth across the target to make sure that we are hitting. When using the "rocking ladder" we must be very careful not to pyramid the spots.

SPOT PYRAMIDING

Spot pyramiding is the application of a new spot before the effect of a previous spot has had time to become apparent. This usually occurs during rapid fire when many salvos are in the air at the same time. Time of flight mechanisms in the rangekeepers and time of flight clocks are used to help the spotter avoid pyramiding by giving him a warning buzzer shortly before the spotted salvo lands.

SPOTTING WITH RADAR

Radar spotting has proved to be both accurate and reliable within the range of surface batteries. Radar provides a means of spotting which is independent of conditions of visibility, so that blind spotting is possible with blind firing.

Shell splashes appear on the scope as fluctuating echoes which last for several seconds, depending on the size of the projectile and the

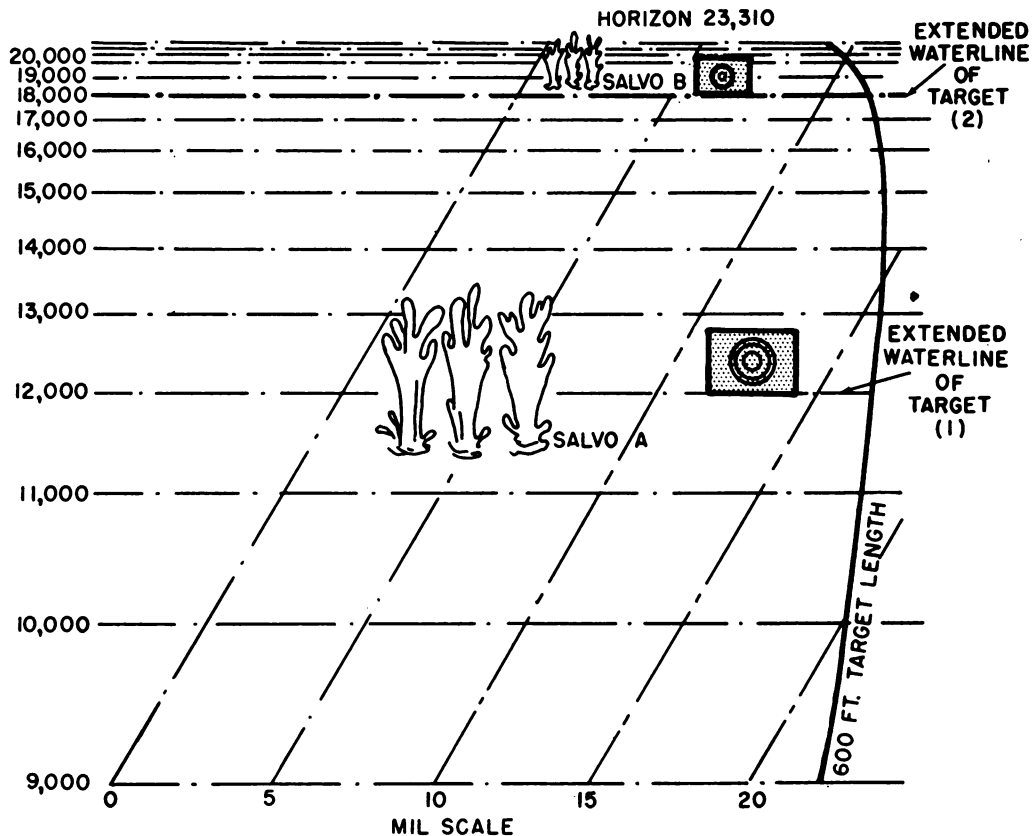


Figure 7-3. —A typical spotting diagram.

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range. The large column of water thrown up by the projectile produces the echo. Salvos produce larger or multiple echoes on the scope.

If the projectile stays within the vertical limits of the radar beam, its flight to the point of impact can be followed on the scope on main sweep. The projectile produces a small, weak, moving echo which begins at the edge of the scope and moves out in range toward the target. At the point of impact the echo stops and grows larger as the splash builds up. Echoes from direct hits or near misses will be lost in the target echo, while salvos which straddle the target may envelope the target in the midst of the splash echoes on the scope, thereby making it impossible to spot individual splashes. Range errors can usually be estimated by radar with greater accuracy than by optical spotting, but deflection spotting with radar is difficult, especially when the error is small. Near misses sometimes merge with and are indistinguishable from the target pip. Consequently, repeated

salvos can land with a 2-mil to 5-mil error which is not separately distinguishable but may not be hits. Target practice is used to determine the minimum deflection error that can be detected on a particular radar. When radar is the only means available for deflection spotting, deflection "rocking ladder" should be used. The order of preference in spotting surface fire is usually: RANGE—radar, air, and visual; DEFLECTION—visual, radar, and air.

SCOPE PRESENTATIONS

It is possible that, with an experienced operator, almost any type of radar can be used for spotting. Here we are only concerned with the radars used in fire control, however. Of these, two types of scope presentations will be discussed, the A-scope and the B-scope.

A-Scope Presentations

The A-scope can only be used for spotting in range. Normally the radar is in precision sweep,

as shown in figure 7-4. With the target in the center of the range notch, the distance from the splash echo to the center of the target echo is the range spot. Figure 7-4 shows the appearance of single shell splashes over and short. Figure 7-5 shows the appearance of salvo fire on the A-scope.

B-Scope Presentations

The B-scope can be used to spot both range and deflection. In using the B-scope for spotting, precision sweep gives the best indications of shell splashes and is used for all accurate spotting. When firing at a long range, or when weak echoes are expected, the receiver gain should be increased to be sure that shell splashes are picked up. For best results, accurate tracking with the target echo kept adjacent to the range line and bisected by the zero bearing line (as shown in figure 7-6) is essential.

On the B-scope of the Mk 13 radar, range spots can be estimated by using the 200-yard bearing line dots as a guide. On the Mk 25 radar a plastic overlay, calibrated with range and bearing lines, is used over the B-scope. Bearing spots can be estimated by using the fractional parts of the splash pips on either side of the center bearing line. Attempts to range or train on the splash echoes will interfere with smooth transmission of target range and bearing.

Keep in mind that even though the direct method of spotting is most often employed when using the radar to spot, it may be advantageous

to use some form of ladder or bracketing method. This may be particularly true on targets at long range or at any time when the splash pips do not build up sufficiently to permit an accurate estimate of range error.

RANGE SPOTTING—B-SCOPE.—As we have stated before, radar spotting has proven to be very accurate in range. Figure 7-7 shows the appearance of single shell splashes on the Mk 13 radar B-scope. The distance from the lower edge of the splash echo to the top edge of the range line is the range spot. The distance between the dotted lines in range is 200 yards. Since the dotted range line may be quite thick, representing as much as 50 yards in range, care must be taken that this factor is included when estimating spots. The range line should be adjusted so that it will be as thin as possible and still be easy to observe. This will reduce the chances of the splash echoes being obscured by the range line, and will permit more accurate spotting.

DEFLECTION SPOTTING—B-SCOPE.—In deflection spotting, using the B-scope, the spotter must know the scope characteristics for the radar he is using. Each radar beam scans a definite arc in bearing. B-scopes show this arc, and therefore, the width of the presentation, in mils, is known. For example, the distance between the bearing lines on the Mk 13 radar B-scope is 50 mils. On the Mk 25 radar the overall deflection of the B-scope presentation is 210 mils.

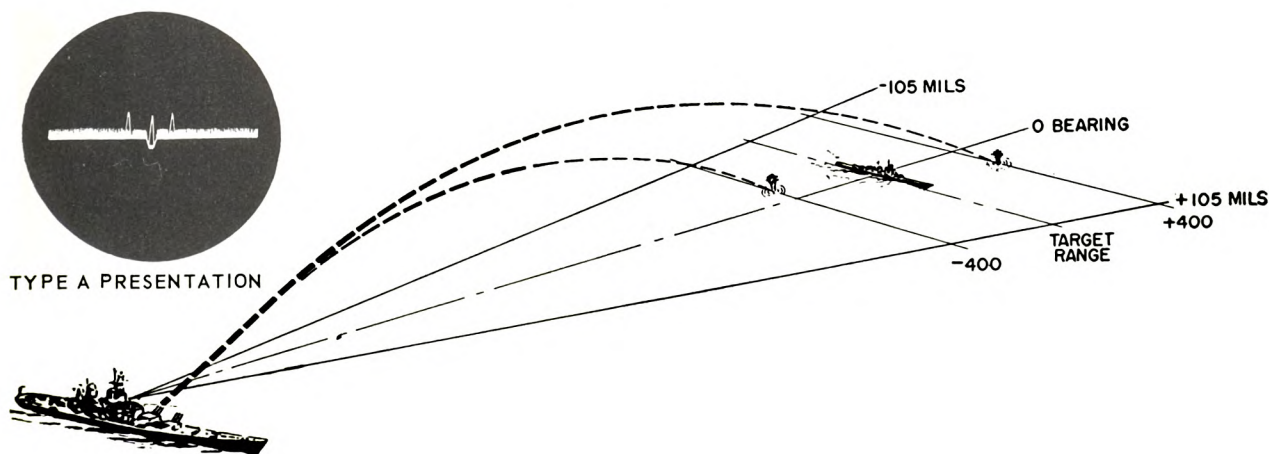


Figure 7-4.—Type A presentation a single splashes 400 yards over and 400 yards short.

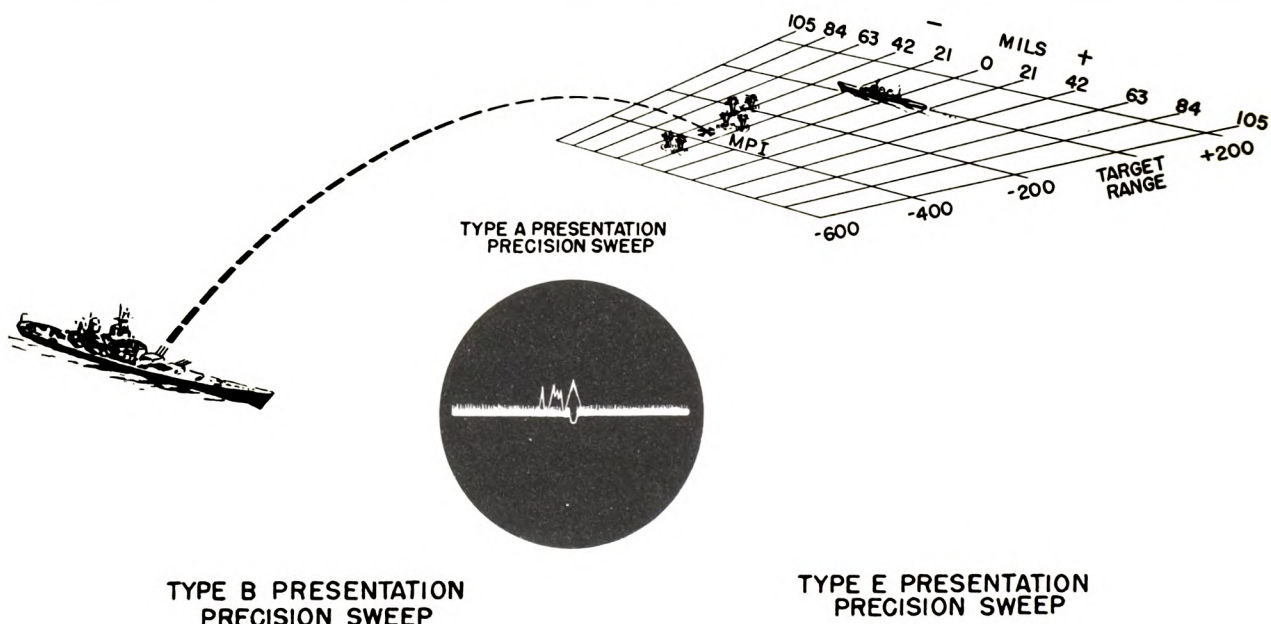


Figure 7-5.—Type A presentation 6-gun salvo.

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With the target in the center of the scope it is possible to spot the fall of shot for a single shell, and the MPI for salvos, directly to the center of the scope. Figure 7-8 shows a B-scope presentation for the Mk 13 radar.

Spotting Salvos

When salvos are fired, several echoes (single or merged) usually are visible on the scope at the same time. With large salvos, shells will probably fall so close together that some individual splashes cannot be distinguished. This may make the spotting of salvos difficult; however, the MPI of salvos can be spotted in a manner similar to spotting single splashes. On the B-scope, the range spot is the average distance of all splash echoes from the top of the range line.

Occasionally large errors in spotting result from lack of discrimination between the echo from the splashes and the echo from the target, or from obscuring of the splashes by the range line. The dotted range line will help to minimize this latter difficulty. The radar spotter should know the number of shots in each salvo and the average range pattern size so that he can more correctly evaluate the picture he sees on the screen when the splashes appear. For example, if two splashes from a 3-gun salvo are within 50 yards of the target, they may not even be detected and the spotter may base his estimate

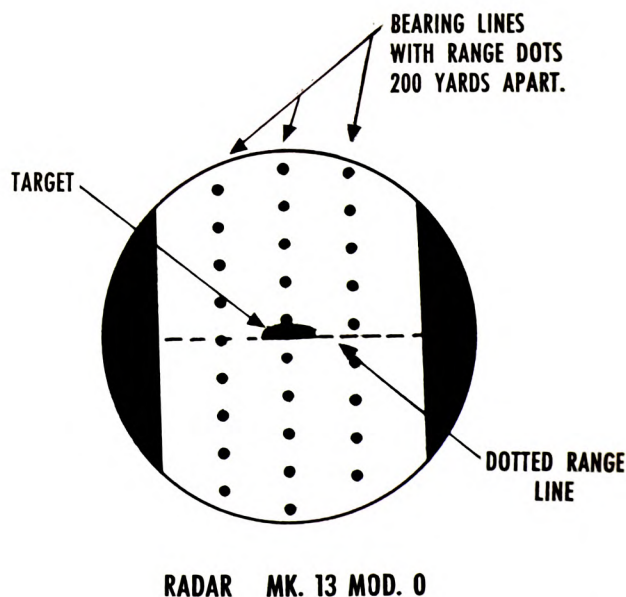


Figure 7-6.—Ranging on target with the B-scope, target centered in bearing.

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of the MPI on the third splash alone (fig. 7-9). However, if he knows that there should be three splashes, and knows what the normal pattern size of such a salvo would be, he can assume that two of the splashes were very close, which

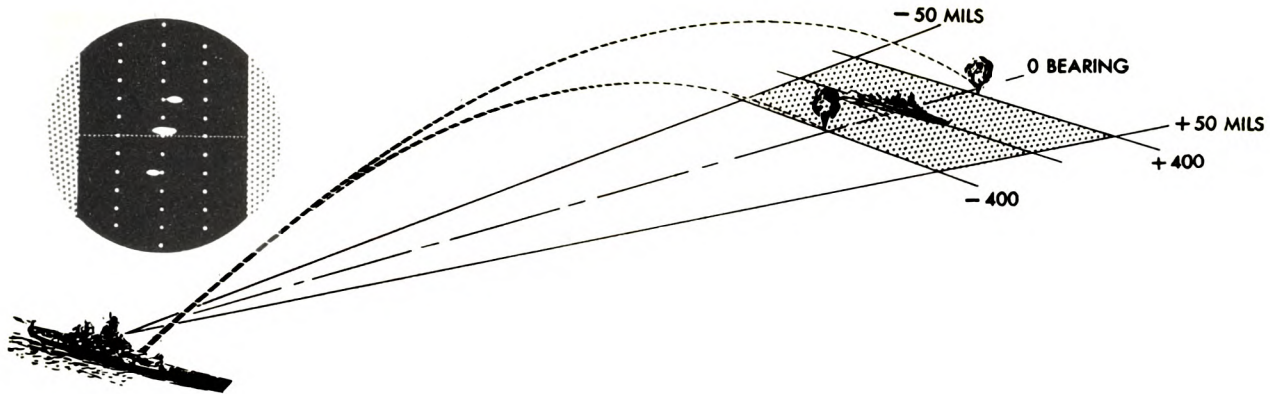


Figure 7-7.—Single shell splashes (400 over and 400 short).

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will result in a smaller and more nearly correct spot of the MPI.

Salvos may be spotted in deflection the same way as single shell splashes. The error of the MPI in deflection is estimated from the appearance of the splashes on the B-scope. Deflection errors are measured in mils to the right or left of the center bearing line of the B-scope. In spotting in deflection, splash echoes may be obscured by the target echo or the range line, as in range spotting. Likewise, several splash echoes may merge and make it difficult to estimate the error of the MPI. Figures 7-9, 7-10, and 7-11, show the MPI of salvos and the deflection errors.

The operator can spot in both range and deflection on the same salvo. Several examples of fall of shot and scope appearances will illustrate the problems involved.

A 9-gun salvo (fig. 7-10) shows the obscuring of the splash echoes with each other, with the target and with the range line. In this instance the range error of the MPI is 152 yards, made up of individual errors in the fall of shot of +396, +371, +42, +133, +177, +54, -29, +25, and -3. The correct range spot is drop 100. Several of the splashes merge into one echo on the scope. None of the splashes near the target appear distinctly on the scope. As a result, the splash echoes appearing on the scope render it impossible to make an accurate radar spot unless the pattern is evaluated correctly. Splashes closer than 100 yards in range and 18 mils in deflection partially merge with the target pip.

Another 9-gun salvo is shown in figure 7-11. The fall of shot error in range and deflection are:

Range in yards

-405
-540
-570
-600
-630
-650
-655
-665
-710

Deflection in mils

L1.5
L2.0
L1.8
L2.0
L2.5
L3.0
L2.5
L2.18
RO.5

The error in MPI in range is -603 yards and in deflection left 2.0 mils. A good radar spot is add 650 and right 2 mils.

SPOTTING ERRORS

Some of the common errors made by spotters are as follows:

1. Too conservative. (SPOT BOLDLY.)
2. Assuming target to be straddled when in reality the bursts are short.
3. Attempting to estimate range errors when the shots are off in deflection. (Always bring the salvo on in deflection before attempting to spot the error of MPI in range.)
4. Deviating from standard spotting doctrine. (Always spot according to the current doctrine.)
5. Pyramiding of spots.

Remember these common errors and be alert to them so that you don't make them when spotting.

GUNFIRE SUPPORT

In Fire Control Technician 3, NavPers 10173-A, we discussed the gunfire support mission, advantages, terminology, and types of fire.

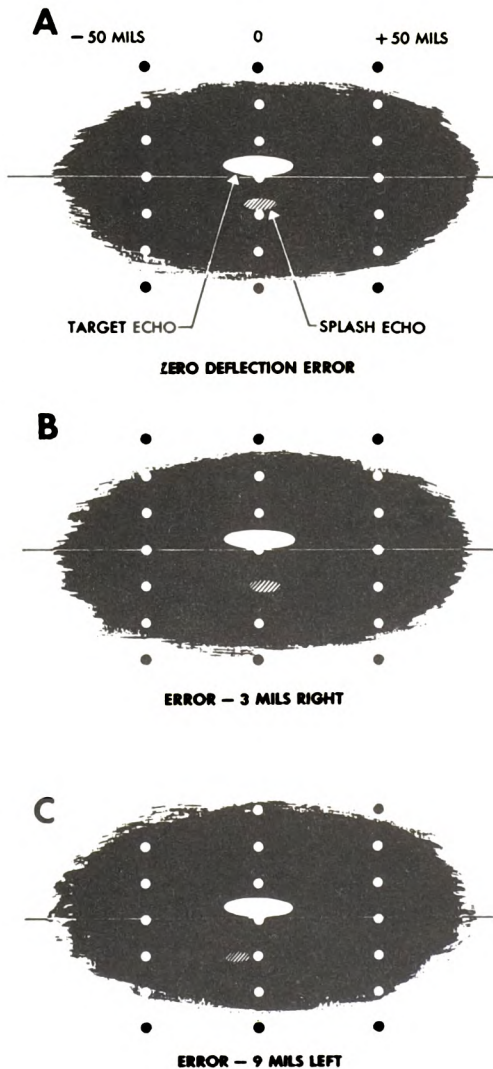


Figure 7-8. —Deflection spotting.

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In this chapter we will discuss more specifically the fire control aspect of shore bombardment methods and techniques.

As far as the Fire Control Technician is concerned, naval gunfire against stationary land targets presents much the same problem as firing at a ship dead in the water (or, with respect to terrain features at a significant elevation above sea level, at a helicopter hovering at fixed altitude over a specific point). The following special aspects of the problem are worth noting.

1. **SHIP'S POSITION.** The geographical position of the firing ship must be continuously

and accurately fixed, as this determines the range and bearing of the target when firing in-direct fire.

2. **CURRENT EFFECT.** The set and drift of the current will affect the solution of the fire control problem. When determined, drift may be entered into the computer as target speed; the direction of the set is reversed and introduced as target course.

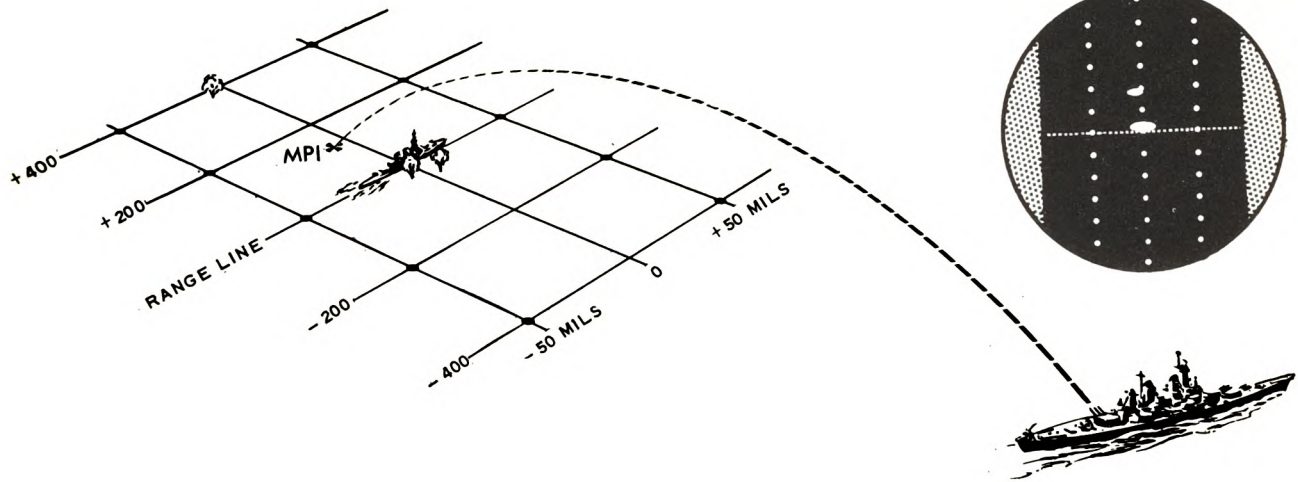
3. **PARALLAX.** Unlike normal gunnery practice at sea, it is sometimes necessary to increase the salvo pattern in deflection in order to cover land targets of large area. One method of doing this is to eliminate horizontal parallax by setting horizontal parallax correctors at the mounts to zero so that gun bore axes are parallel for any specific range.

4. **TERRAIN.** Fire control techniques discussed previously took into account only own ship and target, and the location and velocity of target with respect to own ship. This is necessary because the featureless seascape and the unmarked airspace provide no reference points. On land, however, there are reference points that can be used to assist in laying the guns on the target, and in preventing fire on friendly troops, vehicles, and installations. In addition, terrain features complicate corrections of the fall of shot. Since solutions assume the point of fall to be in the horizontal plane, the elevation of the target above sea level must be considered in the solution. Figure 7-12 illustrates the errors resulting when the range of a land target is taken from a chart and the target's elevation is not considered. Terrain features also affect the size of the pattern in range; a forward slope decreases it and a reverse slope increases it. Figure 7-13 illustrates these effects. Shore bombardment nearly always involves the use of maps and charts to an extent rarely required in other types of naval engagements.

MILITARY GRID REFERENCE SYSTEM

Rapid and accurate means for designating the location of targets are important in shore bombardment. Particularly in naval gunfire support of troop operations, it should be obvious that the troop unit supported and the supporting ship must use a common map, although they need not be of the same scale.

Like other techniques of naval gunfire support, the development of a system of target location designations has passed through several stages, following generally a grid-system



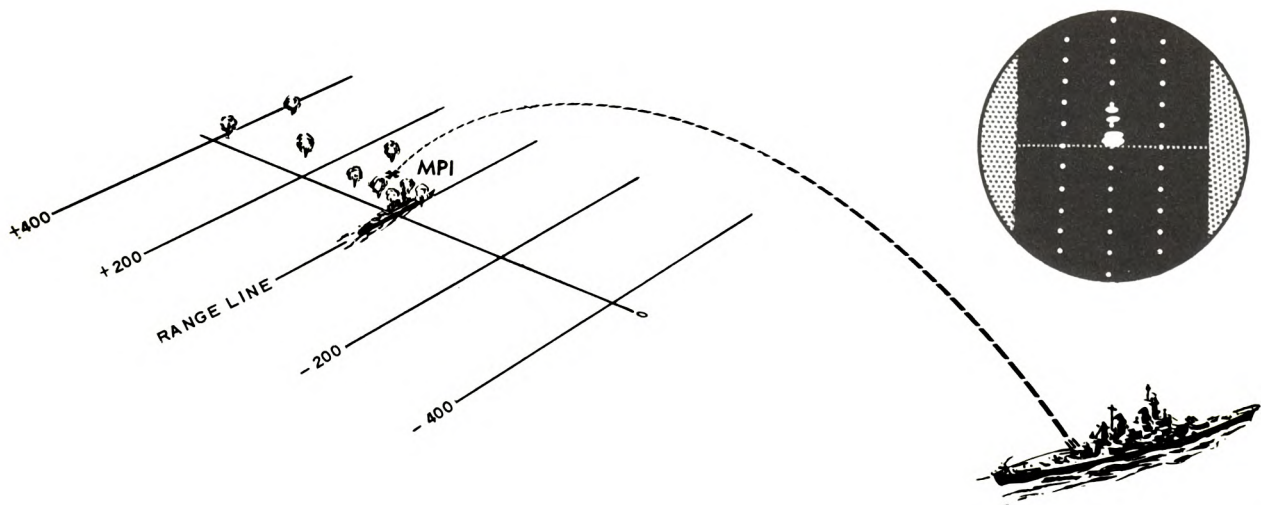
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Figure 7-9. —3-gun salvo with two splashes obscured by the target.

method. In this method, the land and sea areas at the objective are divided into squares by north-south and east-west lines, which are numbered. These lines are called GRID LINES.

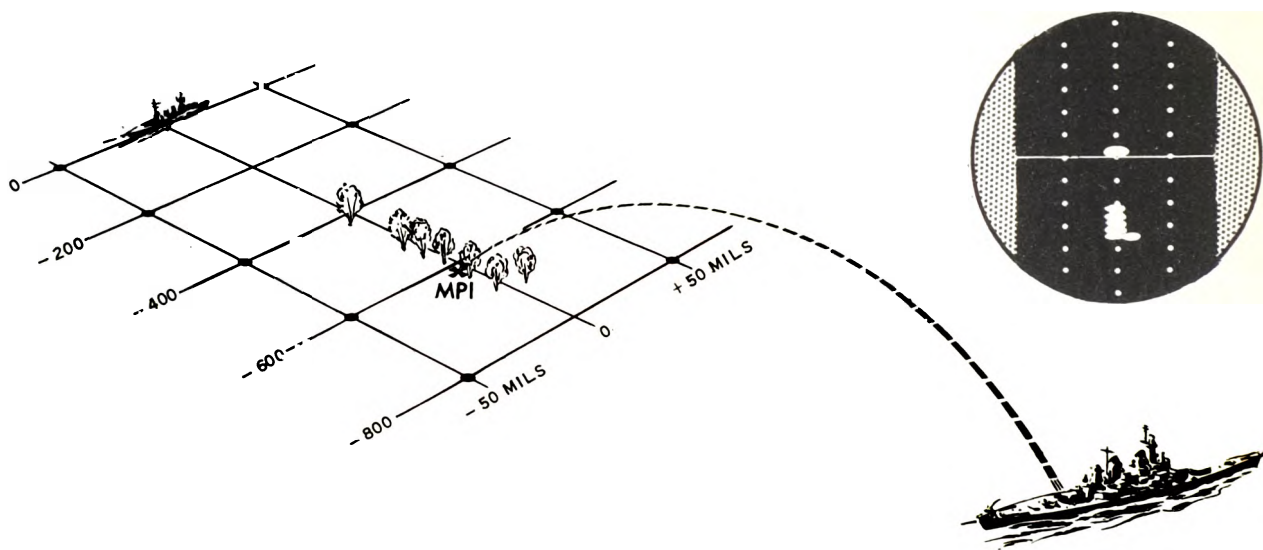
The Military Grid Reference System imposes vertical and horizontal reference lines over a projection of the earth's surface. Its purpose is to simplify and to increase the accuracy of reporting and plotting in military operations. This grid reference system is based on two projections: the Universal Transverse Mercator

(UTM), and the Universal Polar Stereographic (UPS). The UTM is used in the area between 80° south latitude and 80° north latitude; the UPS is used in the polar regions of the earth south and north of these limits. The UTM system divides its area of the earth into a grid pattern with each rectangle in the grid 6° from east to west and 8° from north to south. (Because the grid is rectangular but the earth's surface is not flat, there is some distortion in maps based on the grid, but in any single rectangle this



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Figure 7-10. —9-gun salvo: MPI—152 yards.



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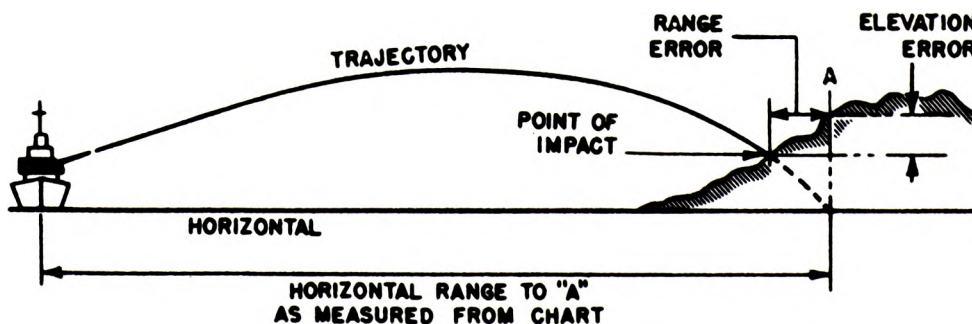
Figure 7-11.—9-gun salvo: MPI—603 yards, left 1.67 mils.

distortion is negligible.) Each rectangle is called a GRID ZONE, and is designated by a letter and a number (e.g., 2P, 5M, etc.). The grid zones are broken down into squares 100,000 meters on a side, and these are further subdivided, with the smallest subdivision a 100-meter square. The subdivisions are systematically identified by letters and numbers, so that in theory any 100-square spot on earth can be designated by its number-letter code. This code is called a MILITARY GRID REFERENCE, and it consists of a group of letters and numbers which indicate (1) the grid zone designation, (2) the 100,000-meter square identification, and (3) the grid coordinates; that is, the numerical reference of the point expressed to the desired accuracy. Examples:

52SCU	Locating a point within a 100,000-meter square
52SCU65	Locating a point within a 10,000-meter square
52SCU6957	Locating a point within 1000 meters
52SCU693578	Locating a point within 100 meters

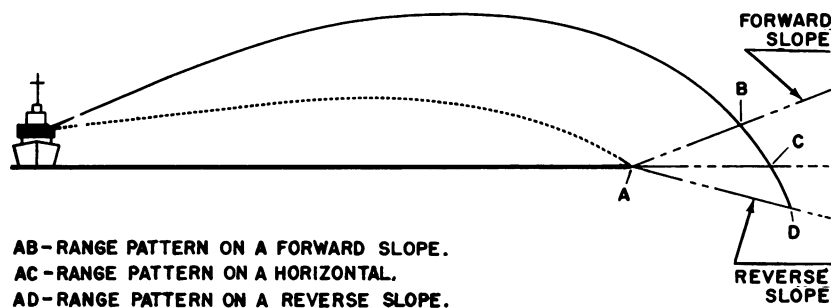
As a matter of practical referencing in a shore bombardment problem, both the grid zone designation and the 100,000-meter square identification are generally omitted.

The UPS system in similar fashion permits location and identification of any 100-meter square on the earth's surface near the poles.



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Figure 7-12.—Errors resulting from failure to compensate for target elevation.



92.67

Figure 7-13. —Effect of terrain slope on the range pattern produced by ship's guns.

Fire support ships are provided with approach charts and bombardment charts for use on their dead-reckoning tracers (DRT) and shore bombardment computers. These charts are complete in hydrographic as well as topographic detail, and both have a grid system overprinted on them. These charts are of particular use in indirect fire. NOTE: A complete description of the military grid reference system is available in Naval Ordnance and Gunnery, Volume 2, NavPers 10798-A.

METHODS OF FIRE

In conventional gunfire control the target is visible from the ship, either optically or by radar. But this is not always true of land targets; much of the firing any ship performs in shore bombardment will be at targets that nobody on the ship can see through a telescope or on a radarscope.

Direct Fire

Direct fire is employed against targets which can be identified visually from the firing ship. These may be point targets, counterbattery targets, targets of opportunity, or area targets.

Upon receipt of target information, the director trains to the designated bearing and locates the described target. Then the mission is conducted as against any surface target with the following exceptions in setup on the range-keeper or computer.

1. Experience has proved that navigational ranges may be more accurate than rangefinder range unless the rangefinder operators are properly trained and "A" and "B" curves are available.

2. Set own ship's speed on zero when ship speed is six knots or less, CIC will determine the actual direction and speed of ship movement (a combination of ship course and speed and set and drift) and send plot reciprocal quantities of these values as target course and speed.

3. Spotting is normally accomplished by the ship's spotter; however, at times better spots may be available from the air spotter or the shore fire control party spotter.

Indirect Fire—Using CIC

Indirect fire is employed against targets that cannot be seen by the firing ship.

Given an accurate bombardment chart and knowing the exact position of own ship, it is possible to measure off range and bearing to any land target that has been designated in advance, and to hit that target without using the director or rangefinder.

The ship's position is accurately determined by navigational methods, using positively identified landmarks, and is plotted on the bombardment chart. Since own ship's course and speed are known, future position may be projected ahead along the ship's track by dead reckoning. Again, as in direct fire, because own ship's speed is usually slow, (less than six knots), the set and drift of the currents frequently contribute as much movement to own ship as do the propellers. To generate an accurate solution it is essential to use total movement of own ship. To ascertain own ship's speed, CIC keeps a continuous plot by navigational methods; after several plots have been made, the distance traveled is measured against time and an accurate value of speed is calculated. This speed is set into the computer by hand as target speed,

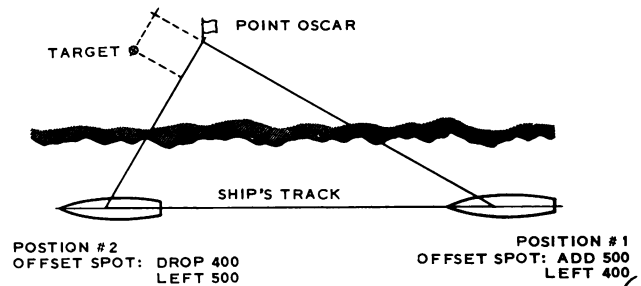
and own ship's speed is set to zero. Target course is then set in manually as the reciprocal of own ship's course.

Future positions are projected ahead along the ship's track on the DRT. A future position is chosen, usually one minute ahead, and from this point bearing and distance to the target are picked off the chart. These values of range and bearing are sent to plot and set into the computer manually. When the ship passes the position chosen, the plotter in CIC gives a "MARK" and the time motor of the computer is turned on. The plotted and computer values of range and bearing are then checked by "MARKING" every 15 or 30 seconds. If the range and bearing agree within reasonable limits (100 yards and 1/2 degree), plot is ready to fire. If not, the check procedure is repeated and the bearing and range in the computer are corrected until the setup is correct. Then plot is ready to fire. Gun Target Line (GTL) should be reported to the shore fire control party. If the target is elevated, target elevation is set on the elevation spot knob in mils, or on the synchronize E knob (OUT position with dip range set initially) in minutes for the computer and with the offset elevation knob in minutes on the rangekeeper.

Upon receipt of spots, the deflection and range spots are converted on the grid spot converter (which will be discussed later). The converted range spot is applied to present range. The converted deflection spot is further converted to minutes and applied to generated bearing. The elevation spot as received from the spotter is converted to minutes or mils and applied to the rangekeeper or computer in the same way as for initial target elevation.

Indirect Fire—Point OSCAR (Offset) Method

In the point OSCAR method of fire (fig. 7-14), the director line of sight is kept continuously on a fixed landmark (point OSCAR) as a point of aim, and continuous ranges are taken to this point. This point can be either a definite landmark or a radar beacon. The target, however, is not usually visible from the ship, and offset spots are applied to the computer solution to hit the target. The value of offset spots in range, deflection, and elevation necessary to move the fall of shot from the point of aim to the designated target must be computed by the DRT plotter and converted, using the grid spot converter, and sent to plot to be introduced into the computer or rangekeeper. For the computer, the



36.31
Figure 7-14. —Point OSCAR Method of indirect fire showing necessity for continuous change in offset.

range spot is applied to the range spot knob; the elevation spot is converted to mils or minutes and applied to the elevation spot knob or to the synchronize E knob; the deflection spot is converted to mils and applied to the deflection spot knob. For the rangekeeper, the range spot is applied to the range correction spot knob, the deflection spot to the deflection correction spot knob, and the elevation spot to the elevation offset knob. If the ship is underway the value of spots must be continuously corrected, because the solution is being generated around point OSCAR instead of the target. The value of total spots in deflection is limited to 180 mils right or left in the Mk 1A computer and 100 mils in the Mk 8 rangekeeper. One way of determining correct range and deflection spots continuously is to use a small transparent overlay on the DRT, on which are inscribed 100-yard squares drawn to the same scale as the chart. With the center of the gridded overlay on point OSCAR, and the grid lines oriented to the direction of the line of sight from the ship, range and deflection spots to hit the designated target may be read directly from the grid overlay.

RADAR BEACON

The radar beacon is a portable transmitter-receiver, set up ashore by the shore fire control party, capable of emitting a characteristic signal when keyed by the transmitted pulse of the ship's fire control radar. This signal is different in frequency from the transmitted pulse, to eliminate the normal echo returns from the shore. This signal is received by the fire control radar when the radar receiver has been tuned to receive the beacon frequency.

Extremely accurate ranges and bearings to the beacon may be obtained. It can be tracked manually or in automatic radar control.

The radar beacon is used primarily to aid in the delivery of accurate naval gunfire under all conditions of visibility and eliminate the errors of normal navigational plotting, using landmarks and navigational aids.

SHORE FIRE CONTROL PARTY SPOTTING

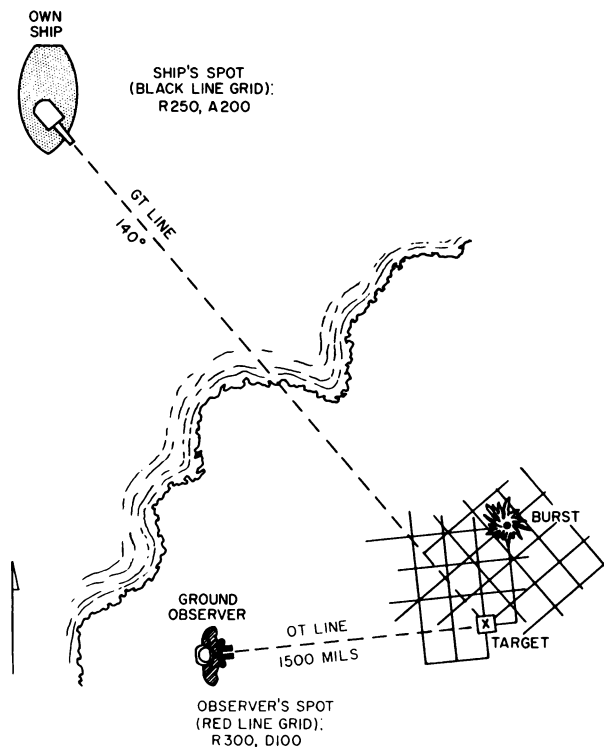
The principles of spotting as discussed earlier in this chapter apply in shore bombardment spotting, but procedures are different when spots are made by a fire control party ashore.

A spotter ashore must be located where he can best observe the fall of shot. Usually this requires him to be as close as possible to the target; this can present him with a very serious front line problem of survival. He also has an alignment problem. Spots made by an observer aboard the firing ship are naturally oriented to the line between the firing ship and target (called the gun-target line). Spots made from aircraft can be oriented readily to the gun-target line, since both the gun and the target are normally within the aircraft observer's field of vision. But spotters ashore are frequently unable to see the firing ship and if they were required to make their spots in relation to the gun-target line, the value of the information sent by the spotter to the ship would be of limited value.

To simplify this problem for the spotter, the TARGET-GRID SYSTEM for use in spotting the fall of shot on land is used. The target-grid system is part of the Standard Spotting and General Shore Bombardment Procedure for use within the naval service.

The system permits the observer to spot the fall of shot just as he sees it along his own line of sight to the target (called the OBSERVER-TARGET LINE), irrespective of the position of the firing ship and of the gun-target line. Using figure 7-15 the procedure is as follows:

1. The observer, in his call for fire, must give the azimuth from himself to the target; direction OT in the illustration.
2. The observer makes all his observations and corrections with respect to the observer-target line (OT).
3. The CIC or plotting room crew converts the corrections with respect to the gun-target line (GT).



59.99

Figure 7-15.—Target-grid spotting problem.

4. These corrections (spots) are introduced into the rangekeeper or computer as previously explained.

GRID SPOT CONVERTER

As stated above, the target-grid system permits the ground observer to call his spots with respect to his own line of sight (OT), while spots introduced into the fire control system are stated with respect to the line of fire. The practical application of the target-grid system depends on quick, accurate conversion of spots in terms of the observer's line of sight (OT) to spots in terms of the line from the gun to target (GT). This is done graphically by the GRID SPOT CONVERTER, which superimposes a set of coordinates based on OT upon a set based on GT.

The converter (fig. 7-16) consists of a transparent circular plastic disc secured by a pivot at its center to a rectangular white plastic piece. Each is printed with a square grid pattern, with the squares on both pieces of equal size, with the words LEFT and RIGHT on either

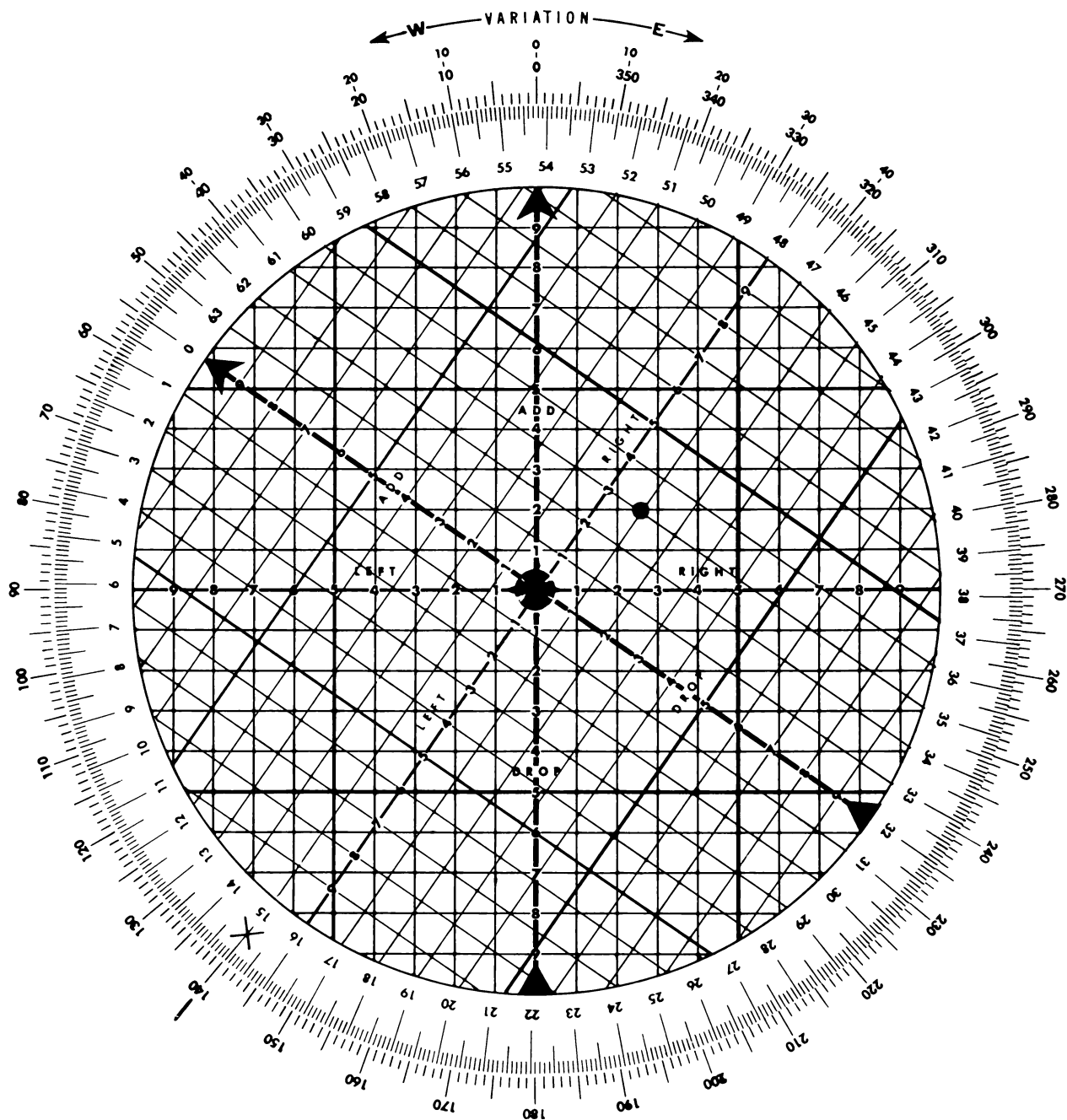


Figure 7-16.—Grid spot converter.

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side and the words ADD and DROP on the upper and lower parts. The grid lines on both pieces are numbered, each square representing an increment of 100 yards.

The grid pattern on the white plastic is printed in BLACK and inscribed in a circle

graduated counterclockwise in degrees; this represents the reference grid for OWN SHIP. On the 0-180° line on this pattern is a black arrow. At the top of the own ship's pattern appears an additional degree calibration for introducing magnetic variation correction.

The transparent pivoted disc has its grid pattern printed in RED. The circumference of its circle (which is concentric with that of the own ship pattern) is graduated counterclockwise in mils. A red arrow is on the 0–3200 mil line. This is the grid reference for the OBSERVER.

Figure 7-16 shows the converter set up for the problem illustrated in figure 7-15. Figure 7-15 illustrates in red the part of the grid pattern that relates to the observer's spots; the black grid pattern relates to own ship line of fire. Magnetic variation is assumed to be zero.

The converter operator obtains the true azimuth of the GT line in degrees by reading the true target bearing from the computer. He makes a mark with a grease pencil at this azimuth on the lower (black) disc. He then obtains the azimuth of the OT line in mils from the observer (spotter) via CIC. He makes another mark at this azimuth on the upper (red) disc.

The operator then rotates the upper disc until the two pencil marks match. (In the figure, GT is 140° and OT is 1500 mils.) The red and black arrows now indicate the angular relationship between the observer's line of sight and the ship's line of fire.

When a spot is received, the operator starts at the center of the upper disc, which represents the BURST, and plots the observer's spot: "Right 300; drop 100," on the observer's reference grid (red), with each square representing 100 yards. The point plotted then represents the TARGET, which is marked with the grease pencil.

He now goes back to the burst (center) and counts off the squares to the target point as projected onto the lower disc (own ship's reference grid). This gives a spot with reference to the ship's line of fire of "right 250, add 200." This is the spot which is applied to the computer. (R250 is in yards and must be converted to mils before it can be applied.) This is done by use of Conversion Scale (spot) Mk 2.

Conversion Scale (Spot) Mk 2

The conversion scale is designed to convert a linear value (yards, feet) to an angular value (mils, degrees, minutes). This conversion is necessary in gunfire support, since spotters transit their corrections (spots) in yards, whereas the computer/rangekeeper bearing and elevation corrections must be introduced as

angular quantities. Figure 7-17 shows the Conversion Scale (Spot) Mk 2. Instructions for operating it are found on the back of the device.

COMPUTERS USED FOR SHORE BOMBARDMENT

Shore bombardment computers are electronic plotting computers which operate in conjunction with the fire control computers in solving the gunfire support problem. They are primarily an electronic DRT, which continuously solves for ranges and for bearings to the target, eliminating all manual plotting. They are fast and give more accurate results. They are particularly effective when used in conjunction with the radar beacon.

Shore bombardment computers are primarily an "indirect" fire control device permitting blind firing directly from bombardment charts. Figure 7-18 shows the relationship between the shore bombardment computer and the main battery fire control system. The computer provides no ballistic data. It fits into the main battery or 5-inch fire control system between the gun director and the ballistic computer. It receives from the navigating or reference director continuous values of bearing and range to

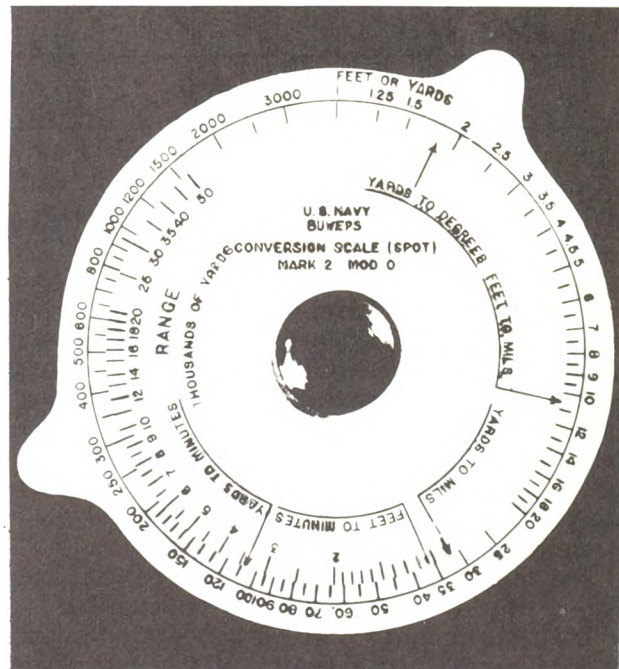
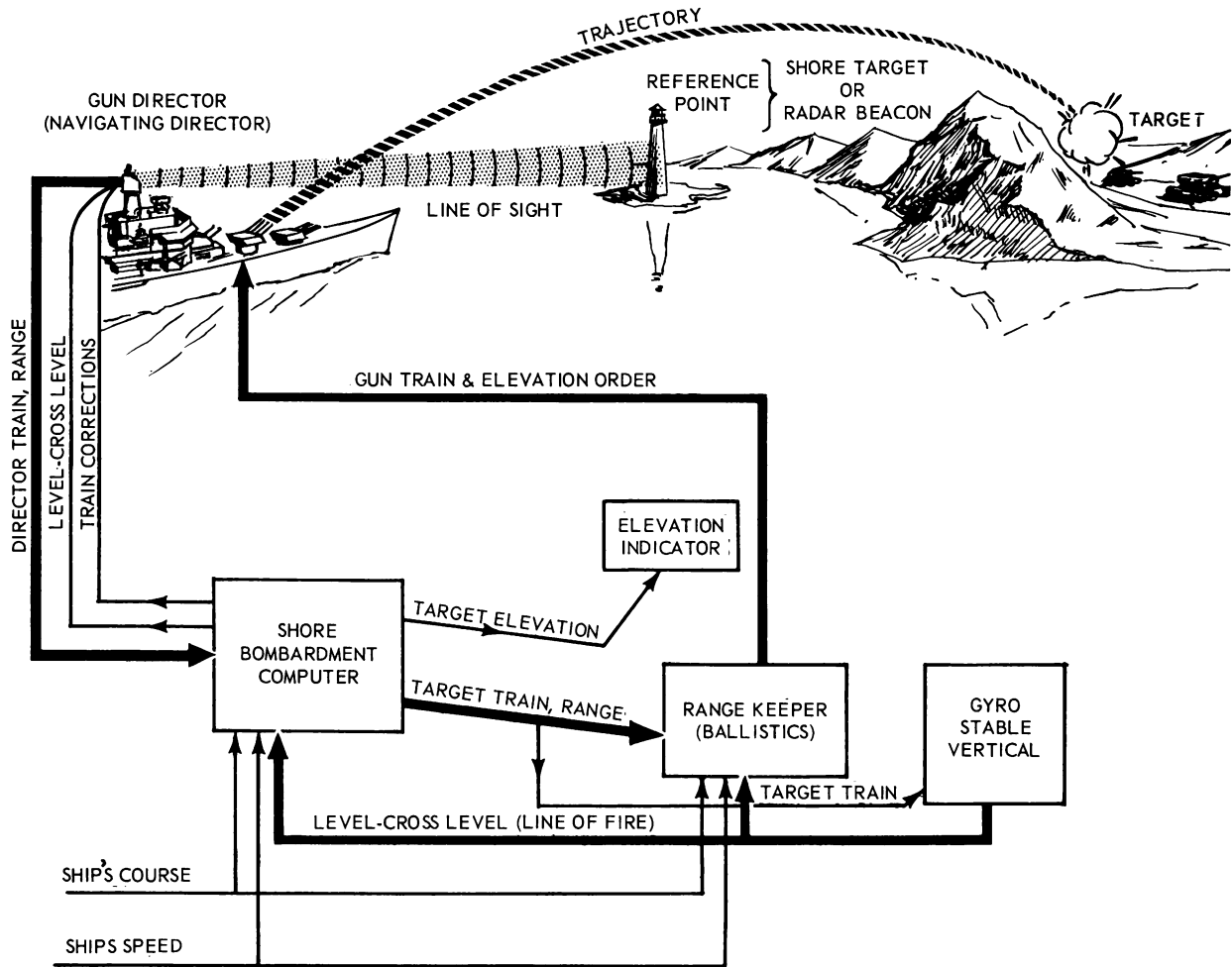


Figure 7-17.—Conversion Scale (Spot) Mk 2.



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Figure 7-18. —Shore bombardment computer—relationship to main battery fire control system.

a reference point of aim (either a shore target or a radar beacon). These values establish own ship position and control the plotting head which continuously indicates ship's track. The tracking head moving underneath a map of the target area carries an indicator light, which when positioned on the target by means of handcranks automatically inserts the offset between the reference point and target.

The computer then computes the bearing and range to the target. These are transmitted to the ballistic computer, which is operated in the normal manner. The height of the reference point and the target are manually set and used to convert slant range to ground range, and vice versa. Basically, the computer is a triangulation

computer which continuously converts bearing and range to a reference point into bearing and range to an offset target.

Since the gun directors train in the deck plane, and thus transmit deck plane bearing information, it is necessary to correct both reference point bearing and target bearing for deck tilt.

The computer also computes stabilization signals of level and crosslevel and an aided tracking signal to the navigating director.

Now let us compare the two methods of firing indirect shore bombardment (CIC giving us navigational data and the shore bombardment computer methods). First, let us consider the time element. In the older CIC method it took

longer to get a solution because the information had to be plotted on the DRT, relayed to the fire control plotting room by telephone, then put in the computer by hand. In using the shore bombardment computer, inputs of range and bearing are automatic, hence a more accurate first salvo solution in less time. Another factor is that set and drift are no longer required, since the shore bombardment computer will automatically and continuously compute own ship's position.

Greater accuracy is obtained by using the shore bombardment computer because the bombardment chart is laid out on the computer and the inputs are made in north-south/east-west coordinates, and the fire control radar is used to establish a known range and bearing reference instead of using navigational or surface-search radar ranges.

Specific information on all phases of gunfire support in amphibious operations may be found in NWIP 22-2.

CHAPTER 8

WAVEGUIDES AND CAVITY RESONATORS

INTRODUCTION

Transmission lines (including waveguides) are treated in Chapter 12 of Basic Electronics, NavPers 10087-A, and in Chapter 6 of Fire Control Technician 2, NavPers 10174-A. Therefore, only the theory and applications not previously treated in detail are included in this chapter. Although rigorous mathematical treatments of the operation of waveguides, cavity resonators, duplexers, and mixers are available in advanced commercial texts, only a simplified treatment is included here.

analogy is not exact and should not be taken literally. In the course of the evolution from a two-wire transmission line to a waveguide the electromagnetic field configurations undergo extensive change. Consequently, the waveguide does not actually operate like a two-wire line shunted by an infinite number of shorted quarter-wave stubs. If it did, only the waves that are four times the length of the stubs would propagate through the tube. Actually, waves of this length cannot efficiently pass through the guide. Only waves of somewhat shorter wavelength (higher frequency) can propagate efficiently.

WAVEGUIDES DEVELOPED FROM TWO-WIRE LINES

The transition from ordinary transmission line concepts to waveguide concepts may be made easier by considering the evolution of a waveguide from a two-wire transmission line. As is pointed out in chapter 12 of Basic Electronics, NavPers 10087-A, a shorted quarter-wave transmission-line stub support acts like an insulator at the frequency transmitted by the line.

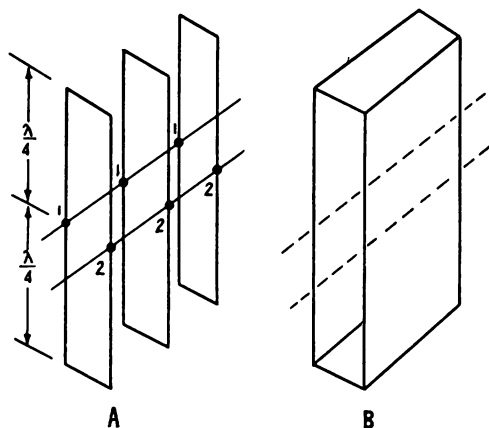
Figure 8-1A shows several shorted quarter-wave stubs connected in parallel across a two-wire transmission line. Because the open-end impedance (at points 1 and 2) of these stubs is extremely high (the ratio of E to I is high), the stubs have negligible effect on the line, and, in effect, act like insulators at the resonant frequency. If an infinite number of these stubs are added in parallel until they touch each other, then the solid rectangular waveguide shown in figure 8-1B is developed.

Now, however, energy is conducted within the hollow rectangular tube called a **WAVEGUIDE** instead of along the two-wire transmission line indicated by the dotted lines. This

BOUNDARY CONDITIONS

Because there is only one conductor (the walls of the guide) in a waveguide transmission system, it is impracticable to talk of the voltage and current distribution as it exists in the two-wire line. The energy that is transmitted is contained in the electromagnetic fields within the waveguide.

In order to choose the proper waveguide for a given job, it is necessary to determine the magnetic and electric fields that can exist in the waveguide. The configuration, or mode, of an electromagnetic field can be determined only if the fields set up by the source and the shape, size, and location of all dielectrics and conductors that are within (or which bound) the field are known. If the conductors and dielectrics are known, it is possible to state the various field configurations that may be excited in the guide. Each of the possible field configurations is called a **MODE**. Thus, the field patterns that may exist in a given waveguide are determined from the shape and size of the waveguide alone. After it has been determined which modes may exist in the guide they are examined to determine which mode will be most useful for a given



67.3

Figure 8-1.—Evolution of waveguide from a two-wire line.

application. A suitable means of exciting the desired mode is then sought.

One condition that must be met by the electromagnetic field within a waveguide is that the field must be continuous throughout the region in which the dielectric is isotropic (having the same properties in all directions). This condition requires that the frequency at which the field oscillates at one point in the waveguide be the same as the frequency at any other point.

There is a second and more important condition: at the surface of a perfect conductor in an electromagnetic field that varies with time, the **ELECTRIC** field (**E** lines) must be **PERPENDICULAR** to the surface, and the **MAGNETIC** field (**H** lines) must be **PARALLEL** to the surface (high-frequency operation is assumed). These **BOUNDARY CONDITIONS** are very nearly true for any good conductor because the low resistance of the good conductor approximates the zero resistance of the perfect conductor.

The electric field orientation that meets the boundary condition is indicated in figure 9-2A, and the magnetic field orientation that meets the boundary condition is shown in figure 8-2B. Although they are shown separately, the electric and magnetic fields occur simultaneously and within the same space.

Stated in another way these boundary conditions become:

1. That part of the electric field **PARALLEL** to the surface of a perfect conductor must be zero **AT THE SURFACE OF THE CONDUCTOR** (fig. 8-2C). In more familiar terms, this condition states that the electric field, which

is equivalent to a voltage, is short circuited when it exists across a perfect conductor.

2. That part of the magnetic field **PERPENDICULAR** to the surface of a perfect conductor must be zero **AT THE SURFACE OF THE CONDUCTOR** (illustrations shown later). In more familiar terms, this second condition indicates that when a magnetic field tends to cut through a conductor a voltage is induced that sets up a current in the conductor. If the conductor is perfect, the magnetic field created by the current is exactly equal to the exciting magnetic field, but of opposite direction. Therefore, the resultant field at the surface of the conductor (and perpendicular to it) is essentially zero.

Unless the width of the conducting plates shown in figure 8-2A and B is extended to infinity, some of the energy established between the plates will escape through the open sides. To contain the energy, sidewalls are added to the parallel plates to form a waveguide.

Many electric field configurations may exist in a waveguide, as indicated in figure 8-2C and D. In each case, however, the boundary conditions must be met. The electric field distribution shown in part C is a half sine wave distribution because a half sine wave occurs across the width of the guide. The electric field is maximum at the center and zero at the sides.

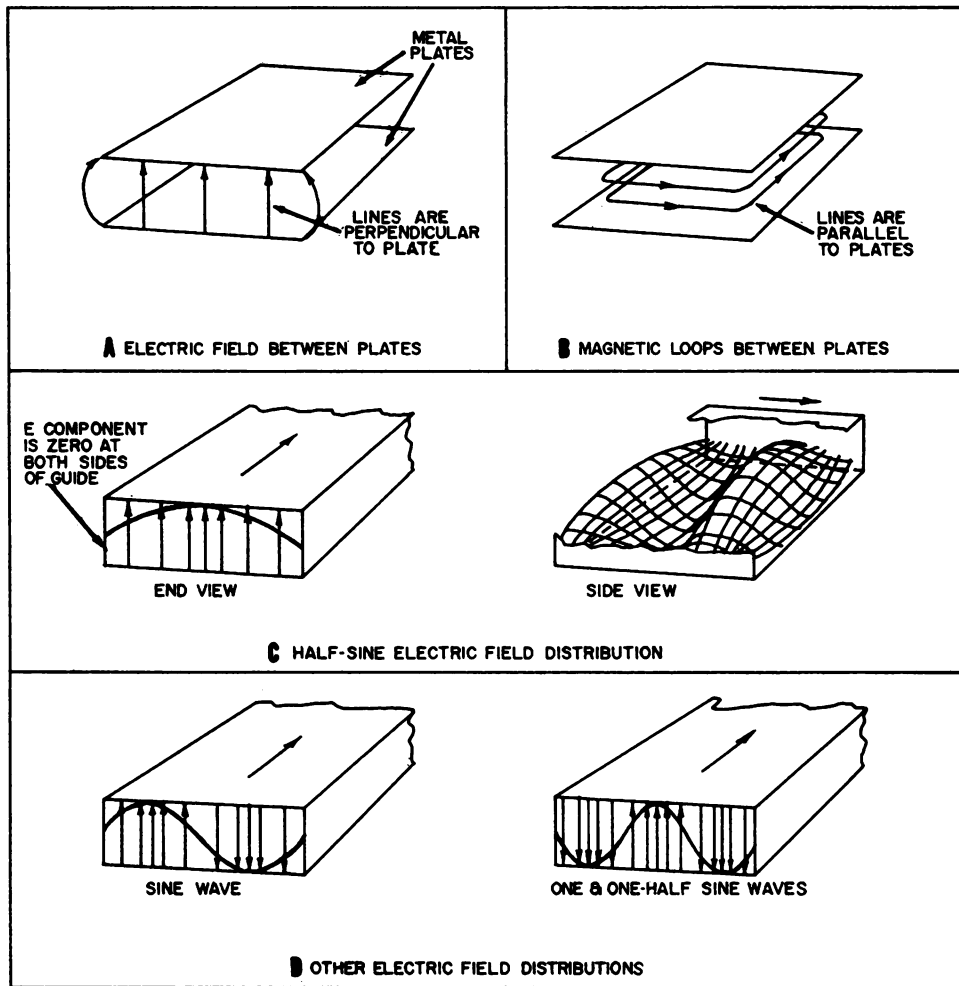
The electric (magnetic, not shown) field varies continuously, and the regions of maximum voltage move down the center of the guide. The field density at the center of the guide increases and decreases sinusoidally (fig. 8-2C, side view), and the electric field at the sidewalls is always zero. Thus, the boundary conditions are met.

A full sine-wave field can also exist in the guide, as shown in figure 8-2D. Again, the electric field strength is zero at the sidewalls. The electric field lines change their direction from positive to negative in a sine-wave pattern. Similarly, one and one-half sine waves may also exist.

WAVEGUIDE OPERATION IN TERMS OF MULTIPLE REFLECTIONS

ANALYSIS IN TERMS OF TWO WAVEFRONTS

A simple analysis of waveguide operation is possible if one assumes two wavefronts traveling



67.4

Figure 8-2.—Field distribution in waveguides.

along the guide and undergoing successive reflections, as shown in figure 8-3. These wavefronts are generated by a dipole perpendicular to the paper and on the axis of the guide at the left end of the guide. Of course, the dipole radiates equally in all directions, but in this case only two wavefronts are shown. The energy thus radiated combines by processes of reflections from the walls of the guide and cancellation in the guide to produce essentially the electric field configuration shown in figure 8-2C. It will be recalled that the electric field at and parallel to the sides of the guide must be zero at all points along the guide. Only the electric field component is considered in this analysis.

A careful study of figure 8-3A indicates that the electric fields add to zero everywhere along

the boundaries (at the sides) but that they add to produce a sine wave in all other planes parallel to the boundaries.

At the boundaries, a crest always coincides with a trough and since they are 180° out of phase and equal in magnitude, the resultant electric field is zero. At any other point along the boundaries where the incident wave is less than the crest, the reflected wave is also less than the crest by the same amount, and 180° out of phase with the incident wave. Hence, the resultant electric field at the boundaries is always zero.

A careful study of figure 8-3A indicates that the electric fields add to zero everywhere along the boundaries (at the sides) but that they add to produce a sine wave in all other planes parallel

GROUP AND PHASE VELOCITY

In order to simplify the explanation of true (group, or energy) velocity and apparent (phase) velocity in a waveguide let it be assumed that the propagated energy consists of individual rays that travel, at the velocity of light c , along the zigzag path shown in figure 8-3B. Simple trigonometry shows that the group velocity V_g at which the energy moves toward the end of the guide is

$$V_g = c \sin \alpha$$

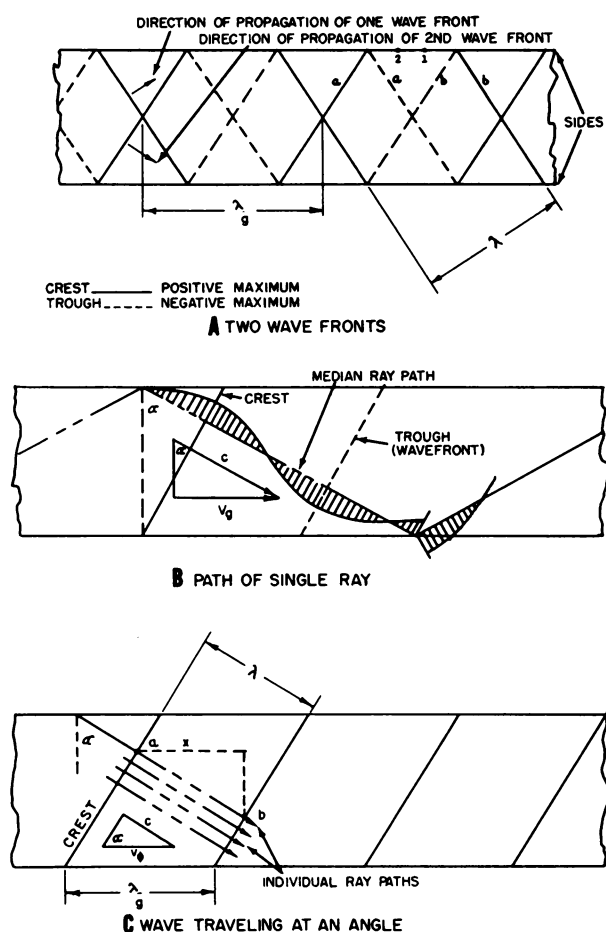
Because the sine of a real angle is never greater than unity, it is evident that the group velocity cannot exceed the velocity of light. In fact, the group velocity is less than that of light for waves of radar frequency because for all such waves α (the assumed angle of reflection of the ray) is less than 90° so long as the waveguide is of finite size.

Now let it be assumed that an electromagnetic wave, which consists of many parallel rays, is traveling along the guide, as shown in figure 8-3C. In order to determine the distance that the energy travels along the guide in one cycle, one must follow a single ray path. In moving along a path from a to b (fig. 8-3C) at the velocity of light, the ray has traveled a distance x along the guide. It is apparent that, as before, the energy has traveled a shorter distance than λ along the guide, and the group velocity is less than that of light.

However, if the actual path of a single ray is not measured, but instead the distance from one crest to the next (of the combined field) longitudinally along the guide is measured, it is found that λ_g (wavelength in guide) is greater than λ (wavelength in free space). The apparent velocity V_ϕ (called phase velocity) is greater than that of light. The guide wavelength (λ_g) from which V_ϕ is computed is measured between corresponding points of the same phase on successive cycles of the wave in the direction of the guide axis. The phase velocity is related to the velocity of light as follows:

$$V_\phi = \frac{c}{\sin \alpha}$$

(The triangle from which this is derived is shown in figure 8-3C.) Because $\sin \alpha$ is never greater than unity the phase velocity is always equal to or greater than the velocity of light.



67.5

Figure 8-3.—Multiple-reflection waveguide analysis.

to the boundaries. To aid in understanding that the waves add to zero along the walls, consider points 1 and 2 in figure 8-3A. Point 1 is midway between the crest of wavefront a and the trough of wavefront b ; it is also midway between the trough of wavefront a and the crest of wavefront b . Point 2 is 45° , or $\frac{\lambda_g}{8}$, away from the crest of wavefront a and 135° away from the trough of wavefront b . Because the sine of both 45° and 135° is 0.707, and because of the phase difference between the crest and the trough at point 2, one wave has a value of +0.707 and the other has a value of -0.707. The combined field is zero. Also, point 2 is 45° away from the trough of wavefront a and 135° away from the crest of wavefront b . Again, the combined field is zero.

Don't be misled. As was shown, the phase velocity is only the apparent velocity of the wavefront. The wavefront is defined as the plane in which the fields are of constant magnitude and phase. (For example, the crest shown in the figures are wavefronts.)

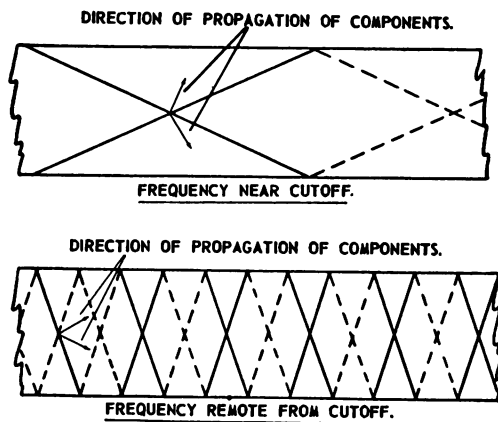
An analogous experience is the speed at which ocean waves appear to move down a straight stretch of beach when they are coming in at an angle slightly off the normal (perpendicular) to the shoreline. The phase velocity is the apparent velocity at which the waves travel down the beach.

The speed at which the waves are moving directly toward the beach is analogous to the velocity c in figure 8-3B.

As has been explained before, the energy is propagated along the guide at group velocity, and this velocity can never exceed that of light. It is this velocity that must be used to compute the length of time required for a wave to propagate through a waveguide of given length. This computation becomes necessary, for example, when it is desired to determine the delay introduced by the waveguide transmission line.

EFFECTS OF CHANGING THE FREQUENCY

Figure 8-4 shows the effect of changing the frequency. Notice that as the cutoff frequency is approached, the direction of propagation of the wavefronts approaches a right angle to the axis of the guide. A careful study indicates that at



67.6

Figure 8-4. —Waveguide paths of components of waves two frequencies.

cutoff (guide width $= \frac{\lambda}{2}$) the component waves will be moving at right angles to the axis of the guide and therefore no energy will propagate down the guide. Notice that the component path lengths (in traversing the length of the guide) increase as the frequency is decreased toward cutoff. At cutoff, the path length becomes infinite. This is the reason attenuation is very great near cutoff, as illustrated in figure 8-5. This figure shows the variation of attenuation with frequency for rectangular waveguides operating in each of three modes and two different width-to-height ratios.

Although skin effect is still present at frequencies slightly above cutoff, and some loss is caused by it, the principal loss is due to path length. As higher frequencies are used, the losses due to skin effect become increasingly important. As illustrated in the figure, the decreased attenuation due to decreased component path length is not sufficient to offset the increased attenuation due to skin effect. Therefore, attenuation rises with frequency.

Figure 8-6 shows the component waves for the case of a TE₂₀ mode in a rectangular waveguide. Other modes may be explained similarly by assuming two or more components, but the configurations become too complex for a two-dimensional drawing. (The mode letter and subscript notation will be explained later.)

ELECTROMAGNETIC FIELDS AND WALL CURRENT (ELECTRON FLOW)

In the foregoing analysis, only the electric field was considered. Every electromagnetic wave is composed of an electric and a magnetic field in time phase with one another. These fields are perpendicular to one another and to the direction of propagation. Their relative directions can be derived mathematically, but, for the purpose here, it is sufficient to know the right-hand rule that relates the directions. This rule states that if the thumb, forefinger, and middle finger of the right hand are extended in such a manner as to be mutually perpendicular, then, if the thumb points in the direction of the electric field and the forefinger in the direction of the magnetic field, the middle finger will point in the direction of propagation. With this rule we can determine the direction of any one of the quantities if the directions of the other two are known.

The right-hand rule may be applied to the two component waves of the TE₁₀ mode of part A

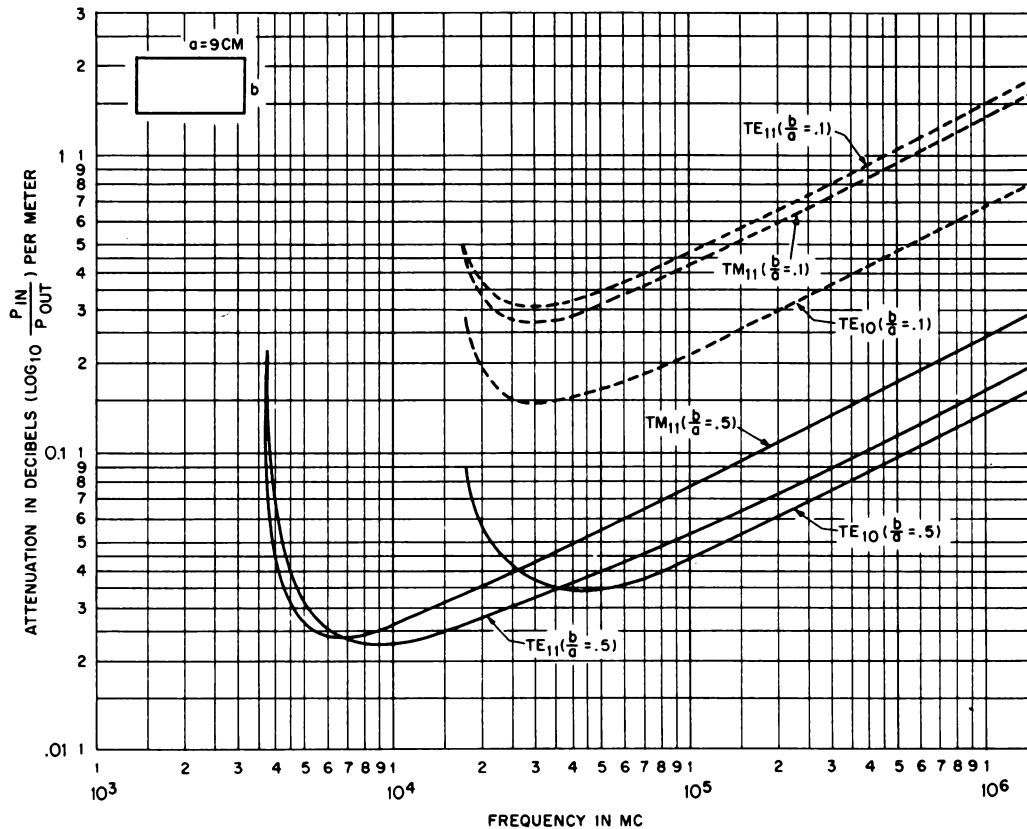


Figure 8-5.—Attenuation vs frequency in a rectangular waveguide.

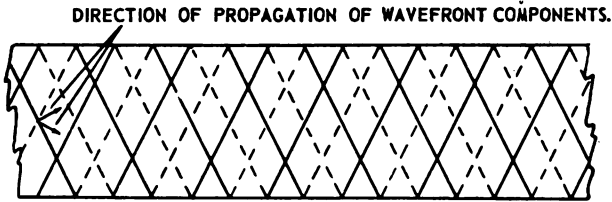
67.7

in figure 8-7. These components are assumed to be originating at the left, possibly from a dipole. The four parts of figure 8-7 are vertically aligned both as regards instantaneous time and location on the guide. The direction of propagation of wavefronts is indicated by the arrows a and b in part A of this figure. At the crest, the electric field is pointing out of the page while at the trough it is pointing into the page. Application of the right-hand rule at the intersections (c and e and immediately to the right or left of d and f in part A of this figure) enables one to determine the direction of the magnetic fields of the two component waves. The relative magnitude of the individual fields and the resultant magnetic field are shown in the figure. Notice that where crest meets crest and trough meets trough the resultant magnetic field seems to be stronger than at the points where crest and trough meet. This does not seem unreasonable if part B of this figure is studied and it is noted that the combined

electric field is also strongest where crest meets crest and trough meets trough.

It is a fundamental law of electricity that magnetic flux lines must always form closed loops; that is, they cannot terminate. The configuration of these loops for the TE₁₀ mode is indicated in figure 8-7C.

Another fundamental law of electricity states that a current is induced in a stationary conductor (surface) that bounds a varying magnetic field. There is a definite relation between the direction of the magnetic flux lines, the direction of motion of the field, and the direction of the induced current (electron flow). This relation may be expressed by the following left-hand rule. Extend the thumb and first two fingers of the left hand so that they are mutually perpendicular. If the thumb is pointed in the direction of motion of the field (toward the boundary) and the forefinger is pointed in the direction of the flux lines, the middle finger will indicate the direction of the induced current. Part D of



67.8

Figure 8-6. —Two wavefront components forming a TE_{20} mode in a rectangular waveguide.

figure 8-7 shows the instantaneous direction of current flow (in the walls of the waveguide) induced by the magnetic field shown in part C of the same figure.

To apply the left-hand rule, the meaning of the expression "direction of motion of the magnetic field" must be understood. The fields within the guide are always trying to expand. They are contained in the guide only because a current is induced in the walls by them, and the field established by the current opposes the inducing fields. Thus, to apply the rule, the direction of motion of the magnetic field is always from the center outward (into the walls).

With this knowledge and the left-hand rule, it is easy to explain the currents shown in part D of figure 8-7. Consider, for example, the points a, b, and c, in parts C and D of this figure. At a and c the magnetic field is zero and the wall current at these points is also zero. According to the left-hand rule a current is induced at b, as shown in part D of this figure.

To the left of point c the direction of the magnetic flux lines is reversed. The field is still moving to penetrate the wall and the induced current is reversed. Similar application of the left-hand rule at other points yields the complete configuration of figure 8-7D. Notice that the current is perpendicular to the magnetic field.

FIELD CONFIGURATIONS (MODES)

In the preceding discussion, mention has been made of TE_{10} and TE_{20} modes. For convenience, script numbers were devised for describing waveguide modes. The letters, TE, indicate a mode of operation in which the electric field lies in planes that are wholly transverse (at right angles) to the longitudinal axis

of the guide. Similarly the letters, TM, indicate that the magnetic field lies in planes that are wholly transverse to the guide axis. The subscript notation for circular waveguides is different from that for rectangular waveguides.

For rectangular waveguides, the accepted system is that the first number subscript indicates the number of half-wave variations of the transverse field in the wide dimension of the guide and the second number indicates the number of half-wave variations of the same field in the narrow dimension. For example, TE_{10} means that the electric field has one half-wave variation in the wide dimension and none in the narrow dimension, and TM_{11} means that the magnetic field has one half-wave variation in both the wide and narrow dimensions.

For circular waveguides, the letters have the same meaning as for rectangular waveguides, but the subscript notation is different. The subscripts have mathematical significance, but they are not readily associated with the field configuration. Figure 8-8 illustrates the field configuration for each of four modes in rectangular waveguides and for each of four modes in circular waveguides. With each, the formula for determining the cutoff wavelength is included. The mode having the lowest cutoff frequency for a given size of guide is called the DOMINANT MODE for that guide. The dominant mode for rectangular waveguides is the TE_{10} , while that for circular waveguides is the TE_{11} mode.

The dominant mode for rectangular waveguides is the mode most commonly used. There are many reasons for this. The mode is easily excited, it is plane polarized, it is easily matched to a radiator, and the plane of polarization is easily controlled. Other reasons are that its cutoff frequency is dependent upon only one of the guide dimensions, while many of the other modes depend on two dimensions, with the result that it is easy to design the waveguide so that only this one mode may exist in it. For dominant mode operation at a particular frequency, attenuation is not excessive when compared with that of other modes in a guide of comparable size.

In case of the circular waveguide, the dominant mode is not generally used as much as the next higher mode. The reason for this is primarily that circular guides are generally used for rotating joints, and this use requires a mode

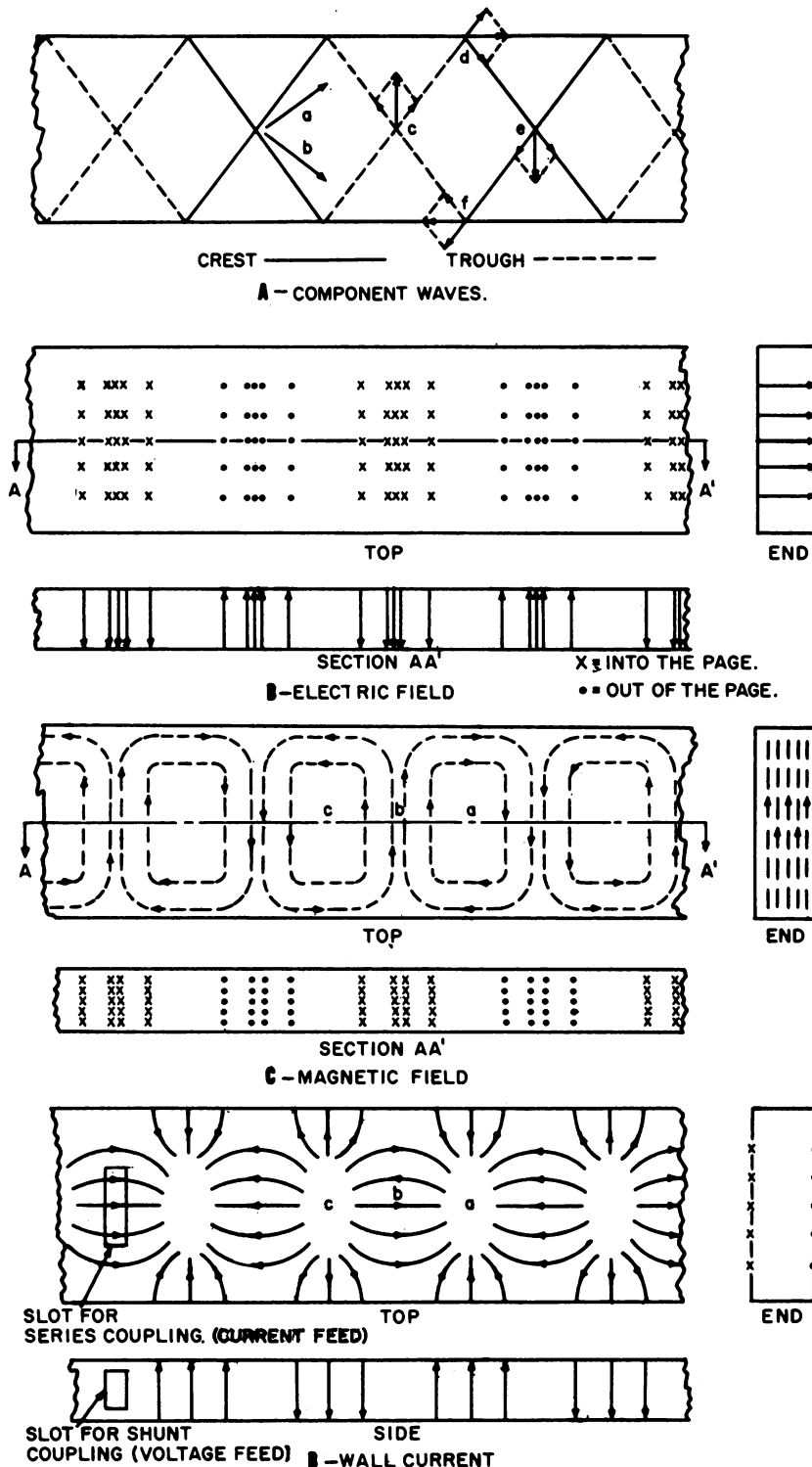


Figure 8-7.—Instantaneous distribution of component waves, E, H, and I in a rectangular waveguide operation in the TE_{20} mode.

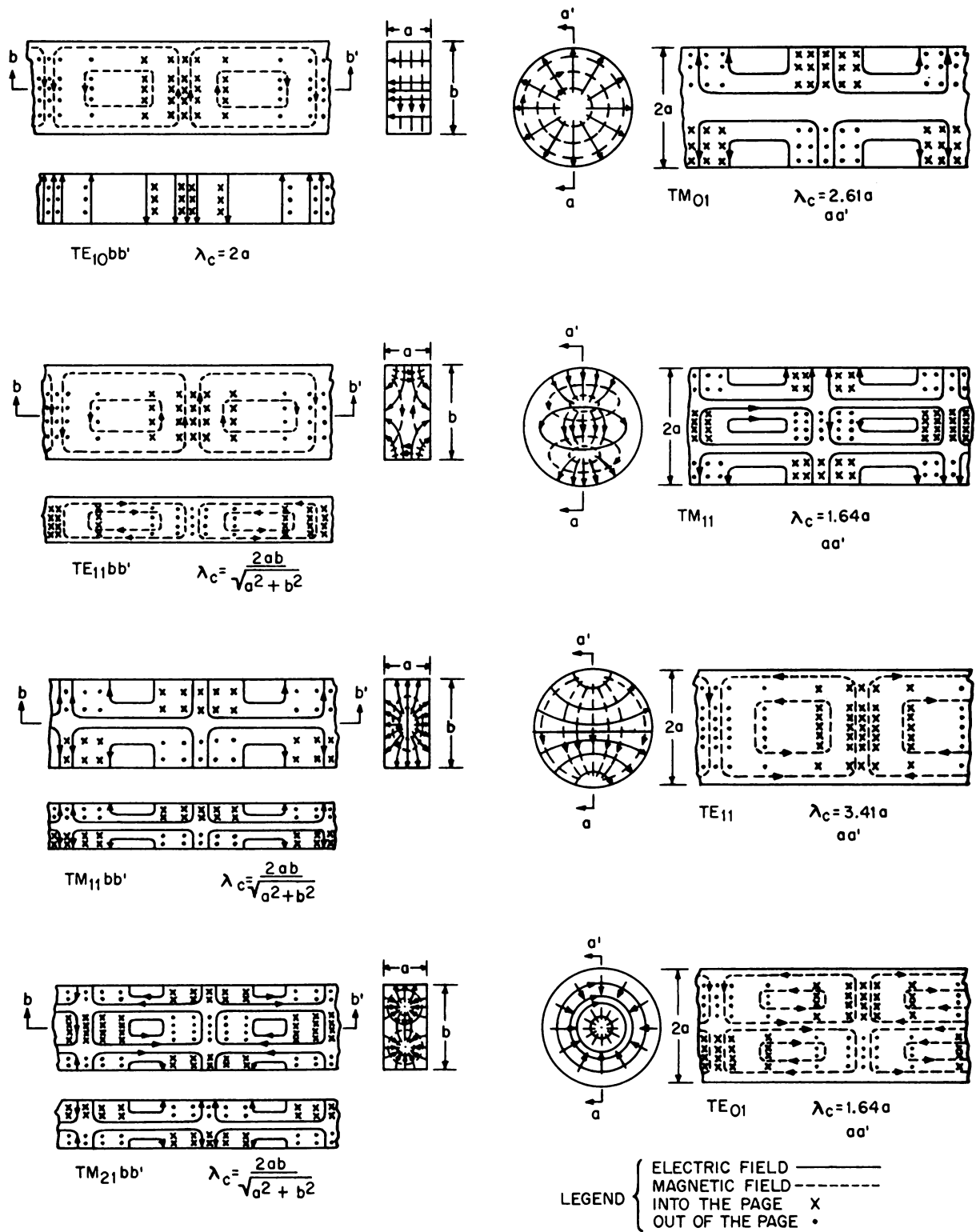


Figure 8-8.—Various modes in waveguides.

having circular symmetry in order to avoid distortion and reflection of the fields as the joint rotates.

RESONANT CAVITIES

The type of resonant circuit commonly used in radio equipment consists of an inductor and a capacitor. As the frequency is increased, the physical size of these so-called lumped circuit elements becomes exceedingly small. For example, it is very difficult, if not impossible, to connect any component into a circuit without introducing at least $5 \mu\mu\text{f}$ of stray capacitance. This means that the minimum capacitance is $5 \mu\mu\text{f}$. To resonate the circuit at 1000 mc would require a $0.00508 \mu\text{h}$ inductor. Such an inductor, if made of a single turn of No. 12 wire, would be less than $1/8$ in. in diameter. (A single straight length of No. 10 wire 1 in. long has an inductance of $0.014 \mu\text{h}$.)

Therefore, at radar frequencies it is impossible to use lumped components. It might seem desirable to use sections of transmission line. The difficulty, however, is that a transmission line open at one or both ends suffers considerable radiation loss. This difficulty can be avoided if we use a waveguide transmission of proper length but closed at both ends.

A waveguide section shorted at both ends is an example of a simple RESONANT CAVITY. Figure 8-9 shows a TE_{10} mode in a rectangular guide and the corresponding rectangular resonant cavity mode. The width of the cavity must be greater than a free-space half wavelength, just as for waveguides. The closed ends must be spaced (distance Y) an integral number of guide half wavelengths. In such a resonant cavity, standing waves may be established in the same manner as they are on two-wire lines. Just as the voltage and current in standing waves on a two-wire line are in quadrature except at loops and nodes, so the electric and magnetic fields in the cavity are in quadrature. This means that the energy is contained alternately in the magnetic and electric fields. It may be recalled that this is like the condition in any resonant tank circuit; that is, the energy alternates between the electric field of the capacitor and the magnetic field of the inductor.

An important difference between the resonant cavity and the resonant tank is that the tank resonates at only a single frequency; whereas, the cavity is resonant at a fundamental frequency and harmonically related frequencies;

and, in addition, many resonate at other frequencies corresponding to other modes of operation. Therefore, a great care must be exercised in order to be certain of single-frequency operation. This is especially important when a cavity is used as a wavemeter.

It should be noted that, at any instant, the current in all of the sides (except the top and bottom) of the cavity shown in figure 8-9 is in the same direction. This is apparent if the LEFT-HAND RULE is applied in a manner similar to that employed for the current in a waveguide wall.

Circular or elliptical guides also may be enclosed (shorted) at both ends to form a resonant cavity. In fact, a volume of dielectric of any shape that is enclosed by conducting surfaces may be used as a resonant cavity. However, the determination of the field configurations becomes very difficult as the geometric configurations of the dielectric becomes more complex. Similarly, it is impossible to set up a simple letter and subscript number system of mode designation that is applicable to all cavities. Figure 8-10 illustrates some of the more common forms of resonant cavities.

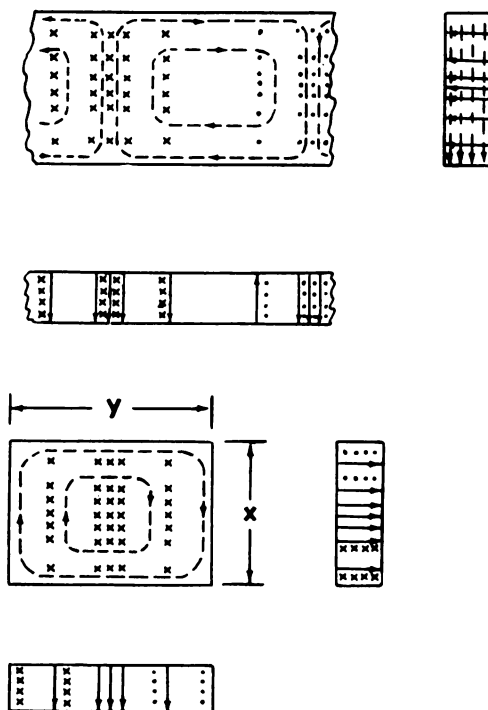
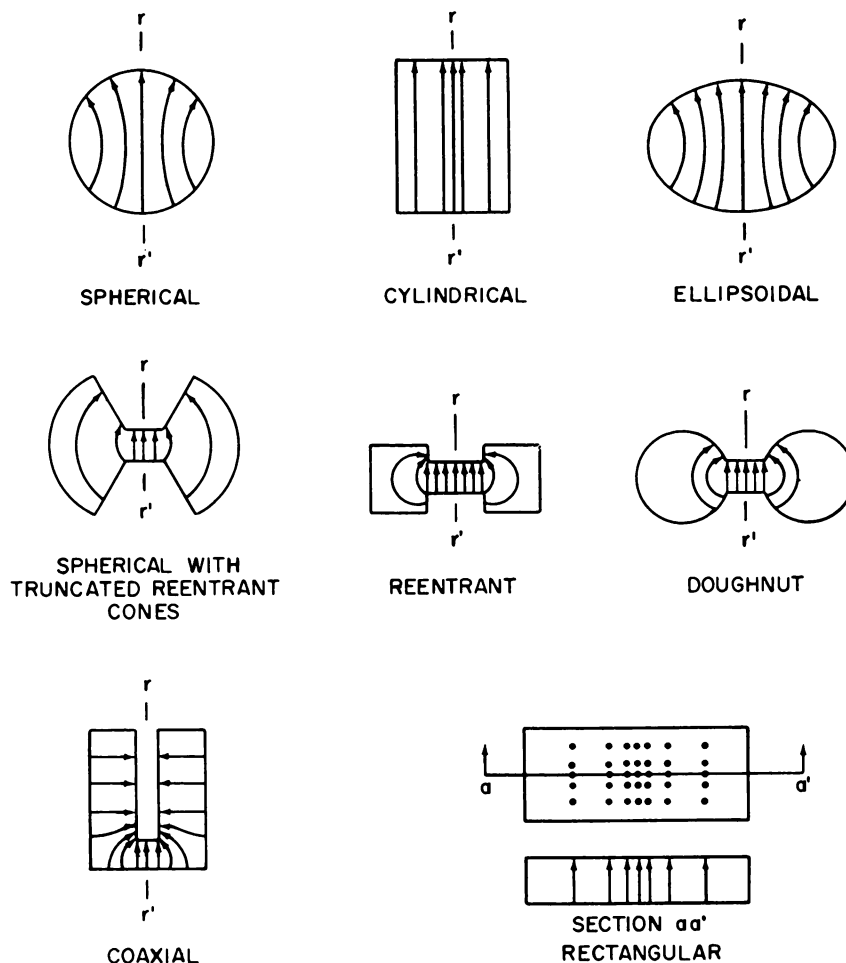


Figure 8-9.—Simple mode in a rectangular guide and in a resonant cavity.

67.10



NOTE: ONLY THE E FIELDS ARE SHOWN. THE LINE rr' IS THE AXIS OF THE CAVITY.

67.11

Figure 8-10. —Some common forms of resonant cavities.

Because of the relatively large conducting surface area of a cavity, the losses are small and the Q is high. Q 's of 20,000 to 50,000 are possible in resonant cavities. (By way of comparison, lumped circuits seldom have a Q greater than 200.) Silverplating the inner surface of the cavity increases the Q (if the plating is not porous) because of lowered I^2R losses. Because the energy is stored in the fields of the cavity and the major losses occur in the surface of the boundary walls, it may be concluded that the greater the ratio of volume to boundary surface area the greater the Q will be. Therefore, simple cavities such as spheres, cylin-

ders, and rectangular boxes usually have higher Q 's than the more complex cavities.

COUPLING METHODS

Waveguides and cavity resonators are useless unless energy can be coupled into and out of them. There are many methods of coupling, but only the more common systems will be discussed in this chapter. The same methods may be used to couple energy into a system as are used to couple energy out of the system. One of the coupling problems is that of introducing

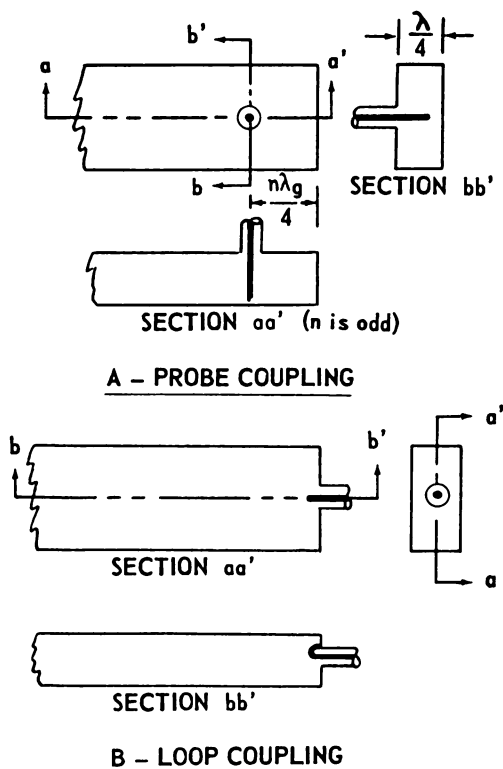
energy from a coaxial line into a waveguide or vice versa. Figure 8-11 illustrates two simple methods of coupling a coaxial line to a rectangular waveguide or cavity.

Probe coupling (coupling to the electric field), shown in figure 8-11A, is widely used. The center conductor of the coaxial line extends into the guide or cavity parallel to the electric field and serves as an antenna. The probe length and sometimes the probe position are adjusted to provide the best transfer of energy. The probe should be located near and parallel to the most dense portion of the E field, as shown in the detailed sketch. In the case of waveguides, one end of the guide is usually closed to establish transmission of energy in one direction only. The closed end is located at the correct distance from the probe so that the reflected wave from the closed end returns to the probe in the proper phase to reinforce the signal being radiated by the probe. This means that the distance from the closed end to the probe is an

odd multiple of a quarter wavelength in the guide.

Loop coupling (coupling to the magnetic field), shown in figure 8-11B, is also widely used. In this case the coaxial line is connected to the waveguide at a point where the magnetic is most dense. As shown in the detailed sketch, the center conductor of the coaxial line is bent to form a loop, which is oriented to link the H lines. The end of the loop is connected to the cavity wall. If variable coupling is desired the loop may be rotated, or its position changed to vary the number of flux linkages.

Figure 8-12 shows three methods of coupling a cylindrical resonant cavity directly to a rectangular waveguide. Part A of this figure illustrates END COUPLING, so called because the cavity is coupled to the end of the guide. Part B illustrates series coupling of a cavity and a waveguide. The slot for series coupling is located so that it cuts the longitudinal wall current path at a point of high current (fig. 8-7D). Thus, the current is forced to flow into the cavity, and series coupling is accomplished. Part C illustrates a cavity that is shunt coupled to a waveguide. In this case the slot is located so that the cavity is coupled to the waveguide by means of the electric field established across the slot (fig. 8-7D). This coupling is called "shunt feed" or "voltage feed" because the voltage is the same on the cavity as on the waveguide at the feed point.



IMPEDANCE MATCHING

When energy is coupled into or out of a waveguide, the proper impedance match between the generator (possibly a magnetron), the coupling elements, the waveguide, and the load (possibly a radiator), must be effected. The waveguide acts like a two-wire line, and unless it is terminated in its characteristic impedance, standing waves are created.

Generally, the proper type of matching element, such as a transformer or a reactive element, are used to effect maximum transfer of energy. Although the same principles of impedance matching are employed in waveguides as are employed in other electrical and electronic devices, the physical appearance of the matching elements is different.

The characteristic impedance of a rectangular waveguide can be considered to be the ratio of the voltage between the top and bottom surfaces of the guide to the current flowing in the

Figure 8-11.—Two simple methods of coupling a coaxial line to a rectangular waveguide or cavity.

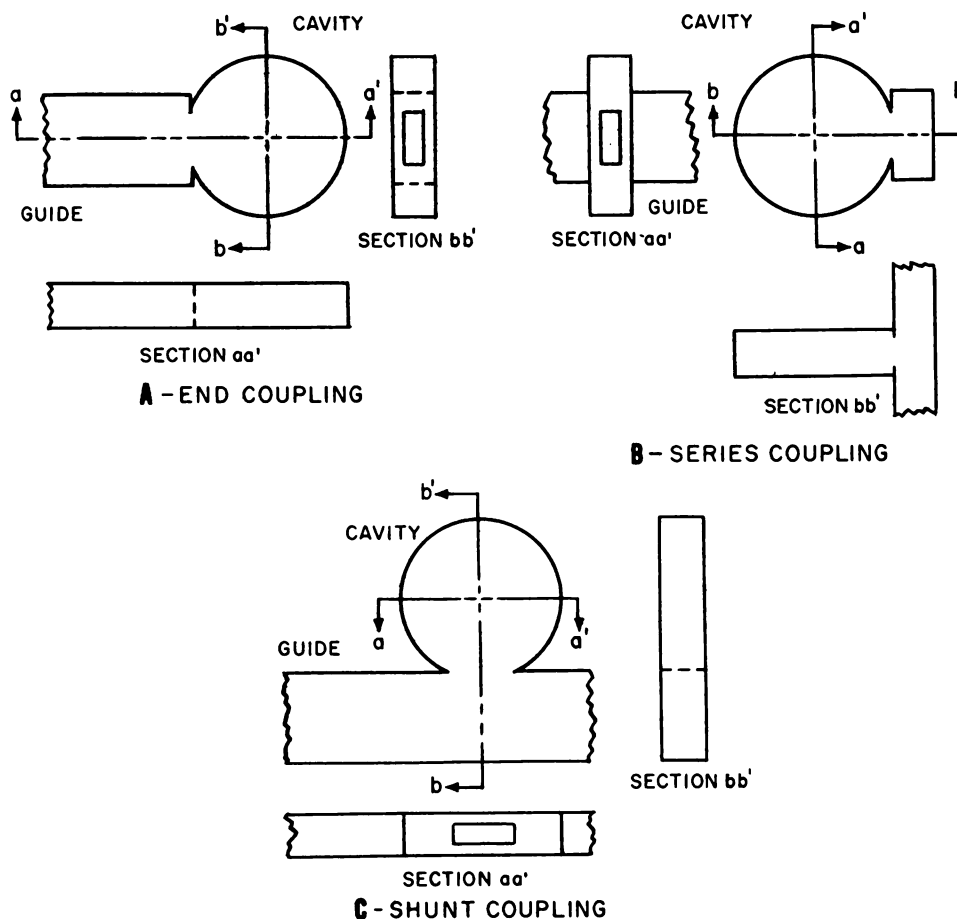


Figure 8-12.—Three methods of coupling a cavity and a waveguide.

67.13

walls of the guide when there is no reflected wave. For the TE_{10} mode with air dielectric, the characteristic impedance is

$$Z_0 = \frac{377 \pi b \lambda_g}{2a \lambda}$$

where Z_0 is in ohms, a and b are the width and height of the waveguide respectively, and λ_g and λ are the guide wavelength and free space wavelength respectively. The lowest characteristic impedance obtainable in a circular guide is about 350 ohms, but it may vary in a rectangular guide from 0 to 465 ohms, depending on the dimensions and modes.

A waveguide may be made to act as a radiator by the simple expedient of leaving one end of the guide open. This method is not very satisfactory, however, because the energy is

radiated in a broad beam and there is considerable reflection within the guide. The reflections occur at the open end because of a lack of impedance match, and standing waves are established in the guide.

If the open end of the waveguide is flared in the shape of a horn, the impedance match of the guide to free space is considerably improved, less energy is reflected back along the guide, and energy is radiated in a more concentrated beam. To obtain a very sharp beam, the flare must be gradual and the mouth of the horn must be very large. To fulfill both of these requirements, the horn must be very long, and therefore this method is not very desirable. Essentially, the horn constitutes an impedance-matching section between the waveguide transmission line and the earth's atmosphere, which

may also be regarded as a waveguide. Thus, the horn is a transition section between a small and a large waveguide.

Whenever it is necessary to connect waveguides of different sizes together, the sudden change in size may cause reflections. One means of avoiding this is to use a tapered section (horn) to make a smooth transition. Such a tapered section is shown in figure 8-13. The more gradual the taper, the better is the transition. Tapered sections may also be used for transition between waveguides of different shapes—that is, rectangular and round.

Another method of achieving an impedance match when joining two waveguides involves the use of a resonant cavity. The cavity may be coupled to the waveguides by means of slots. Proper choice of the location and shape of the slots makes it possible to match impedances. This method of coupling has the disadvantage of being frequency sensitive.

When connecting two waveguide sections, it is often necessary to turn corners or to rotate the fields of the guide so that they are in the proper direction for matching. Figure 8-14A, shows two examples of a 90° elbow in a rectangular guide, and part B shows a 90° twist for rotating the field through 90° .

If it is necessary to join two waveguide sections in such a way as to allow for expansion or movement, a choke joint is usually used. Figure 8-15 illustrates choke joints for rectangular and round waveguides. Into the choke flange is cut a circular slot a quarter wavelength deep. The flange is designed so that the middle of the broad face of the waveguide is a quarter wavelength from the edge of the slot, point M in figure 8-15. The short circuit at the bottom of the slot, A, reflects as a high impedance at B. This high impedance is transformed to a low impedance at C because of the quarter-wave line from B to C. Thus, the choke joint effectively connects D and E even though there is no direct metallic connection between them. The

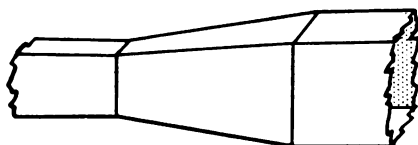
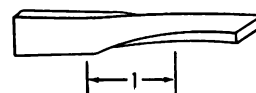


Figure 8-13.—Tapered waveguide transition section.

67. 14



A - RADIUS r SHOULD BE GREATER THAN 2λ .



B - LENGTH l SHOULD BE GREATER THAN 2λ .

67. 15

Figure 8-14.—Elbows and twists in rectangular waveguides.

choke joint is relatively ineffective at points, such as P and Q, because a high impedance is reflected between the ends of the two waveguides at these points. However, because r-f voltage is very low at these points there is little tendency for energy to leak out of the joint.

The choke joint for a rectangular guide is thus fully effective only at the point where the r-f voltage is a maximum. The choke joint for a round waveguide, however, is very effective because the distance from the waveguide to the edge of the slot can be made a quarter wavelength all around the guide. This same arrangement can be used with round waveguides to allow one guide to turn relative to the other as well as to permit the two pieces of the guide to slip axially. Two choke flanges, as indicated in the round waveguide coupling, are more effective than one.

Impedance characteristics of waveguides may be changed by the use of metal partitions called irises or windows. Consider the example shown in figure 8-16 for the TE_{10} mode in rectangular waveguides. The partition shown in part A of the figure is called an INDUCTIVE WINDOW because its presence causes local fields to be set up, which are predominantly magnetic.

The window shown in part B of the figure causes local fields to be set up, which are predominantly electric, and is known as a CAPACITIVE WINDOW.

A RESONANT PARTITION has the form shown in figure 8-16C. It acts like a parallel circuit in shunt with the waveguide. All of these partitions find use in impedance-matching applications as well as in the design of filters.

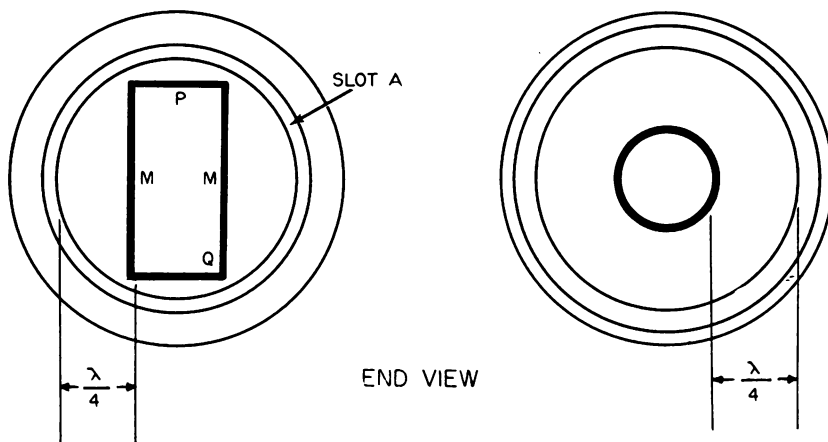
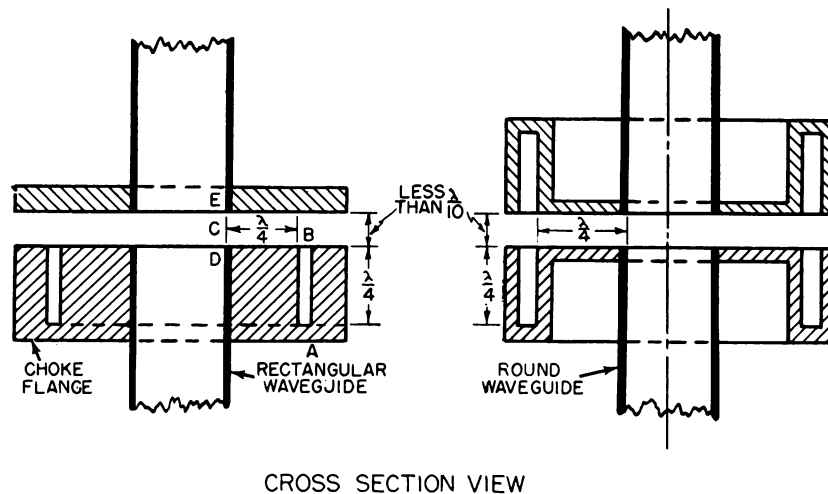


Figure 8-15.—Choke joints in waveguides.

67.16

Another problem of impedance matching is that of terminating the waveguide without radiation or reflection. This is important, for example, in a directional coupler. Figure 8-17 shows two methods of terminations. In part A of the figure, a longitudinal partition of resistive material is introduced to absorb the incident energy. The partition is tapered to prevent reflection—that is, to achieve an impedance match.

Figure 8-17B illustrates the use of a transverse partition of resistive material. To be effective, this partition should be located at a quarter wavelength ($\frac{\lambda_g}{4}$) from the shorted end

of the guide and it must have a resistance-per-square equal to the wave impedance of the guide. (Wave impedance is the ratio of the

strength of the transverse electric field to that of the associated magnetic field. Resistance-per-square means the resistance measured between the two surfaces of a thin sheet of resistive material.)

DUPLEXING SYSTEMS

Whenever a single antenna is used for both transmitting and receiving, as in a radar system, there arises the problem of ensuring that maximum use is made of the available energy. The simplest solution is to use a switch to transfer the antenna connection from the receiver to the transmitter during the transmitted

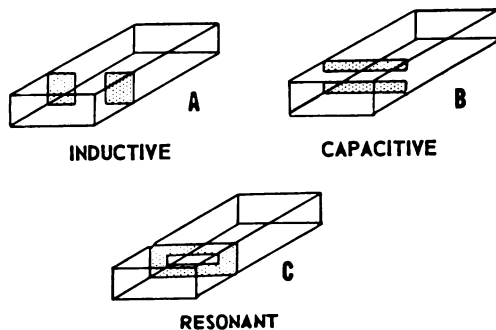


Figure 8-16.—Partitions in rectangular waveguides. 67.17

pulse and back to the receiver during the return (echo) pulse. There are no practical mechanical switches available that can open and close in a few microseconds, and therefore electronic T-R (transmit-receive) switches must be used.

In selecting a switch for this task, it must be remembered that protection of the receiver input circuit is equally as important as the power considerations. At frequencies where r-f amplifiers may be used, the amplifier tubes can be chosen to withstand large input powers without damage. However, at microwave frequencies the crystal mixer at the input circuit of the receiver is easily damaged by large applied signals, and accordingly must be carefully protected.

In general, if the receiver input circuit is properly protected the remaining receiver circuits can be prevented from blocking as the result of strong signals. A very strong main pulse signal still appears in the receiver output unless additional precautions are taken to eliminate it. This can be done by a receiver gate signal that turns on the receiver during the desired time.

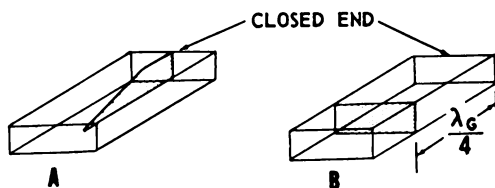


Figure 8-17.—Waveguide terminations. 67.18

OPEN-WIRE T-R SWITCH

In the T-R method of switching, the switching function is performed by a spark gap, as illustrated in figure 8-18. The spark gap makes a reasonably good switch because it is an open circuit until sufficient voltage is applied to cause the gap to arc over. The arc is formed when the air between the electrodes ionizes. Once the arc is formed, the voltage required to maintain the arc becomes very low, and the resistance of the gap may be of the order of 30 to 50 ohms. The voltage across the ionized gap is independent of the applied power, and the resistance varies increasingly with applied power. Air at atmospheric pressure requires about 30,000 v per in. of gap to start the arc, while the running voltage (voltage below that at which the arc will be extinguished) is much lower. The breakdown and running voltages for enclosed gaps depend on the pressure and the gas or vapor used.

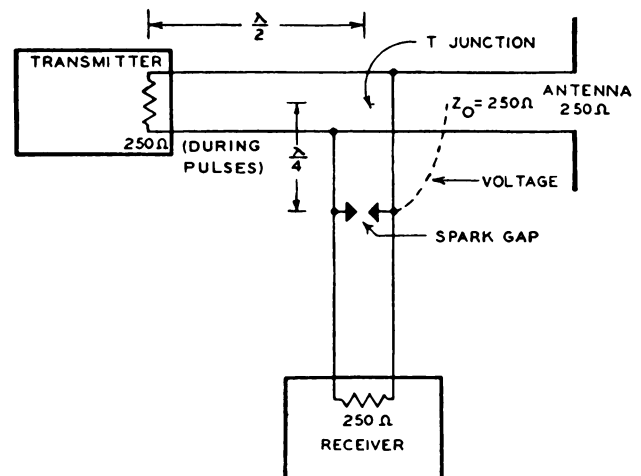


Figure 8-18.—Open-wire T-R switch. 67.19

For purposes of illustration, it will be assumed that the characteristic impedance of the transmission line, the feed-point resistance of the antenna, the input impedance of the receiver, and the output impedance of the transmitter (when generating r-f power), are all 250 ohms. The transmitter output impedance rises between pulses to 5000 ohms. The resistance of the conducting gap is 50 ohms.

The pulse from the transmitter reaches the T junction where it finds two paths to follow. Part of the pulse power goes down the receiver branch and causes the spark gap to break down. As a result, a resistance of 50 ohms is placed

across the 250-ohm line a quarter wavelength from the T junction. As seen from the T junction, the quarter-wave line terminated in 50 ohms appears as a much higher impedance of:

$$Z_{in} = \frac{Z_o^2}{Z_{out}} = \frac{250^2}{50} = 1250 \text{ ohms.}$$

The pulse therefore has a choice of a 1250-ohm path to the spark gap or a 250-ohm path to the antenna. (The antenna terminates the transmission line in its characteristic impedance.) The pulse energy divides so that most of the energy takes the lower resistance path to the antenna, while the rest is used to keep the gap discharging. Because the receiver branch is a resonant line, there will be a voltage distribution across it, as shown in figure 8-18. The voltage across the gap is lower than that across the T junction, and, in fact, is the pulse voltage that reaches the receiver because the rest of the receiver line is properly terminated by the receiver input. If the gap resistance can be made lower, the magnitude of the pulse reaching the receiver will be reduced, and the T-R action will be improved. The lower gap resistance will also require less power from the T junction.

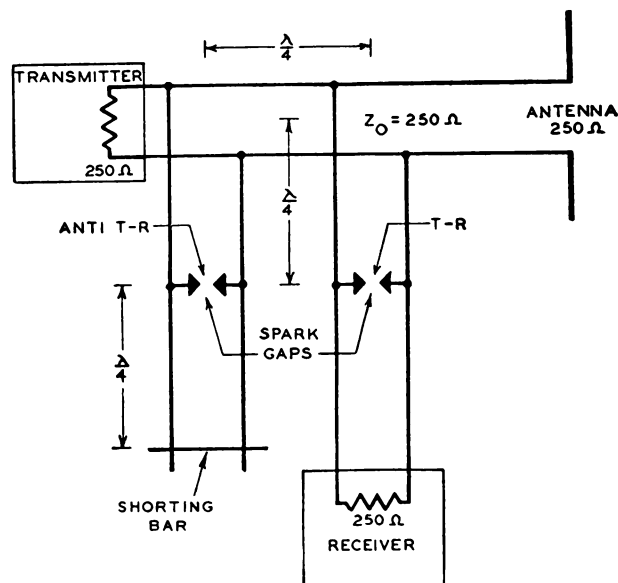
At the end of the transmitted pulse the gap is deionized. When the echo signals picked up by the antenna reach the T junction there is a choice of two paths, one to the transmitter and the other to the receiver. The receiver path has an input impedance of 250 ohms because the spark gap is an open circuit and does not affect the impedance of the receiver branch. The path from the T junction to the transmitter is made a half wavelength, and is terminated in 5000 ohms (the output impedance of the transmitter between pulses). The half-wave section acts as a 1:1 transformer so that the received signals at the T junction "see" 5000 ohms, looking toward the transmitter. The received signals are divided, and practically all of their energy takes the low-resistance path to the receiver.

ANTI-T-R SWITCH

The output impedance of the transmitter does not always change sufficiently (from the energized condition to the de-energized condition) to permit the use of a half-wave resonant line to prevent received signals from reaching the transmitter. In such cases, a second spark gap is used as an antitransmit-receive switch to block the transmitter branch at the receiver T junction. Figure 8-19 shows the T-R system

of figure 8-18 with an anti-T-R switch added. The T-R switch works in the same way as in the system just described.

The transmitted pulse passes down the line to the anti-T-R spark gap and causes it to arc over. The resulting short circuit is reflected back to the main feed line as a high impedance by the quarter-wave line. If the same values are used as in the previous example, the reflected impedance of the anti-T-R gap will be 1250 ohms in parallel with the 250-ohm antenna line. During the transmitted pulse, then, the anti-T-R switch simply uses a small amount of the transmitted power.

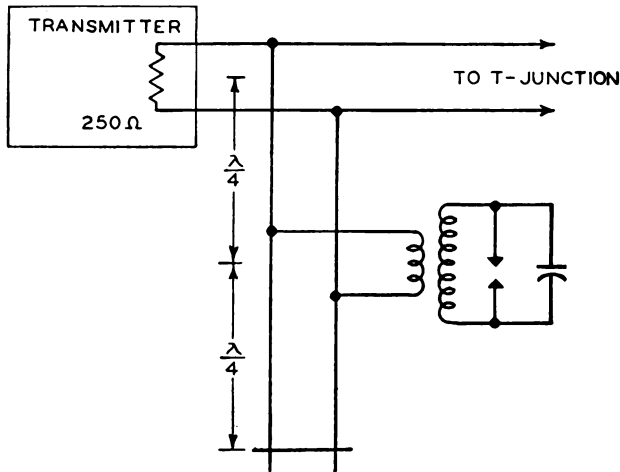


67.20

Figure 8-19. —Anti-T-R switch.

The anti-T-R gap is effectively an open circuit during the resting period. The short circuit at the shorting bar, which is a quarter wave below the gap (fig. 8-19), is reflected by the half-wave anti-T-R line as a short circuit across the transmitter feed line. This short circuit is reflected in turn to the T junction of the receiver T-R switch as a high impedance by the quarter-wave section of the line, thus blocking this channel to received signals; therefore they travel down the line to the receiver.

Both the T-R and the anti-T-R switches require some of the transmitted-pulse power to operate them. This requirement is undesirable because a part of their function is to increase the over-all efficiency. The amount of power required can be somewhat reduced, and the



67.21

Figure 8-20.—Anti-T-R switch with transformer.

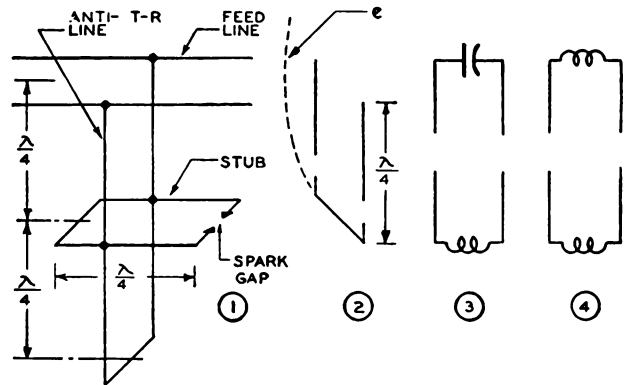
switching action improved, by using transformers to step up the voltage applied across the gap. Suppose that the signal is applied to the primary of a step-up transformer, and the spark gap is placed across the secondary (fig. 8-20). The secondary is parallel tuned to obtain a very high secondary impedance when the gap is not conducting. This impedance is reflected in shunt with the primary as an open circuit.

The echo signal voltage applied to the primary is stepped up in the secondary and thus causes the spark gap to break down sooner than it would if the original signal were applied directly to the gap. The resistance of the conducting gap is placed across the tuned secondary and is stepped down into the primary as a much lower resistance. Assuming a gap resistance of 50 ohms, and an impedance ratio (secondary-to-primary) of 10:1, the primary will have an impedance of 5 ohms. The 5 ohms is reflected by the quarter-wave line as:

$$Z = \frac{250^2}{5} = 12,500 \text{ ohms.}$$

For equal echo signal amplitudes the power taken by the gap will be reduced to one-tenth of the power used when the gap is placed directly across the line.

Transformers of the ordinary r-f type will not function well at the carrier frequencies



67.22

Figure 8-21.—Resonant-line transformer anti-T-R.

used in radar, but a resonant line can be used as an excellent autotransformer to produce the same results. Figure 8-21, (1) shows an open-wire line that uses a quarter-wave stub to step up the voltage applied to the anti-T-R spark gap and to step down its conducting resistance across the anti-T-R line. The stub can be considered as two sections of transmission line (fig. 8-21, (2)), one of which is terminated in a short circuit, and the other in an open circuit. The shorted line is less than a quarter wave long, which gives it an input impedance that is inductive. The open line, also less than a quarter wavelength, is a capacitance. The two are in parallel, and because their reactances are equal, they form a resonant circuit of very high impedance (fig. 8-21, (3)). During the resting time, with the gap extinguished, a stub having high impedance has very little effect in bridging the anti-T-R line.

When energy is applied to the stub, a standing wave of voltage that is maximum across the gap is set up along its length. The received signals are normally not large enough to break down the gap. The transmitted pulse is large enough, however, and places a low resistance across the open end of the stub by causing the gap to conduct. The stub now consists of two lines in parallel across the anti-T-R line, each of which is inductive (fig. 8-21, (4)). The result is to place a very low inductance across the anti-T-R line a quarter wavelength from the feed line, reflecting the low impedance as a very high impedance to the feed line to limit the energy to the small amount necessary to operate the gap.

COAXIAL T-R SWITCH

The effectiveness of a T-R switch is dependent on having a spark gap resistance of relatively low magnitude compared to that of the characteristic impedance of the associated transmission line. It was pointed out in the preceding discussion that resonant lines acting as transformers can be used to decrease the apparent gap resistance. When coaxial lines are used, resonant transformers are required to lower the effective gap resistance because the impedance of a coaxial line is only about 60 ohms as compared to a gap resistance of 30 to 50 ohms.

A simple form of coaxial T-R system is shown in figure 8-22. The magnetron is matched to the coaxial line by the tuning stub during the transmission of a pulse. The length of the transmitter branch is adjusted so that the impedance seen at the T junction "looking back" toward the magnetron is high when it is not generating r-f energy. The received signals therefore take the low-impedance path to the receiver. The receiver feed line is broken by the insertion of a 1:1 transformer in the form of a half-wave line shorted at both ends.

The half-wave line (fig. 8-23) is similar to a tuned circuit and has an input impedance that is zero at the short circuit (at each end), and increases to a maximum in the center when the gap is not energized. The magnitude of the impedance depends on the Q of the half-wave

line, and the connected load, which in this case is the receiver. The coaxial lines on either side of the half-wave line are connected to it at points that match the coaxial-line characteristic impedance. The receiver input circuit terminates the feed line in its proper impedance, so that for received signals the receiver branch of the transmission-line system is matched throughout. This condition produces maximum signal (echo) energy to the receiver.

The half-wave transformer has a spark gap between the inner and outer conductors at the middle of its length. A portion of the transmitted pulse passes from the T junction down the receiver feed line to the resonant half-wave line where it develops a large voltage at the center. This large voltage breaks down the gap, the resistance of which effectively short circuits the center of the half-wave line. The receiver feed line at point A then "sees" two short-circuited lines (to the right and left of point A), each less than a quarter wave long. The resulting impedances are inductive and in parallel, and they present a very low impedance to the feed line at point A. The receiver feed line branch (fig. 8-22) is adjusted in length to present the low impedance of the half-wave line (at point A) as a high impedance at the T junction when the gap arcs over. The voltage across the gap before arc-over occurs is stepped up by the half-wave line to a high value without increasing the voltage applied to the receiver input. The use

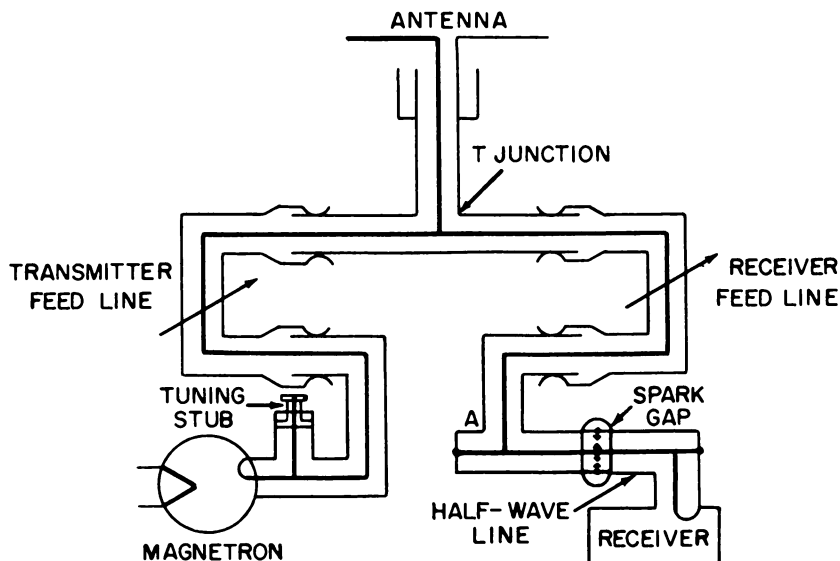


Figure 8-22.—Coaxial T-R switch.

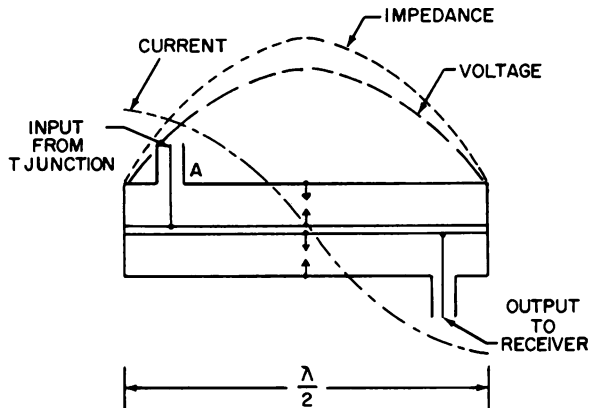


Figure 8-23.—Half-wave line T-R switch.

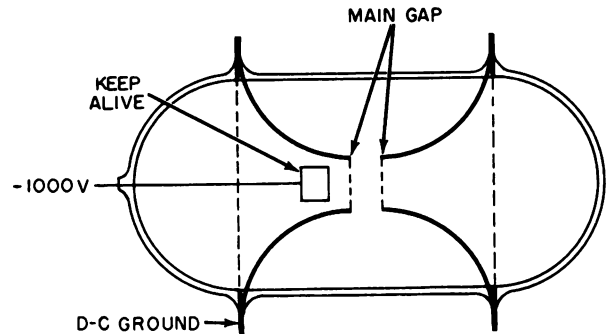
of the half-wave line therefore reduces the effective gap resistance, and thereby lowers the power necessary to operate the T-R switch and reduces the energy delivered to the receiver.

At microwave frequencies the transformer half-wave coaxial line is reduced to such small dimensions that it becomes practically a cavity, and it is usually so constructed. The use of a cavity gives a higher Q for the transformer and thus improves the over-all operation.

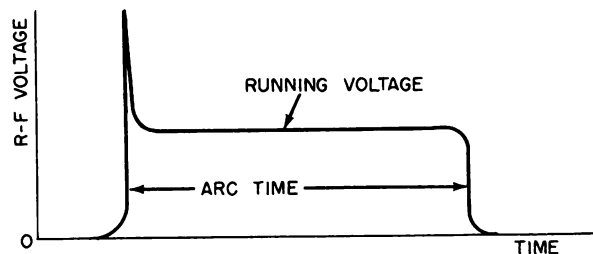
T-R SPARK GAPS

The spark gap used in a given T-R system may vary from a simple one formed by two electrodes placed across the transmission line to one enclosed in an evacuated glass envelope with special features to improve operation (fig. 8-24A). The requirements of the spark gap are that its resistance shall be very high until the arc is formed, and then be very low during conduction through the arc (fig. 8-24B). At the end of the transmitted pulse the arc should be extinguished as rapidly as possible to remove the loss caused by the arc, and to permit signals from nearby targets to reach the receiver.

The simple gap formed in air has a resistance during conduction of from 30 to 50 ohms. This is usually too high for use with any but an open-wire transmission line. The time required for the air surrounding the gap to be completely deionized after the pulse voltage has been removed is about $10 \mu\text{s}$. During this time the gap acts as an increasing resistance across the transmission line to which it is connected. However, in a T-R system using an air gap, the



A T-R TUBE WITH KEEP-ALIVE ELECTRODE



B ENVELOPE OF R-F VOLTAGE ACROSS GAP IN T-R TUBE

67.25

Figure 8-24.—T-R tube and characteristics.

echo signals reaching the receiver beyond the gap will be permitted to increase to half their proper magnitude $3 \mu\text{s}$ after the pulse voltage has been removed. This interval is known as **RECOVERY TIME**.

The magnitude of voltage necessary to break down a gap and the running voltage during the time of the arc can be lowered by reducing the pressure of the gas surrounding the electrodes. T-R tubes are therefore used in which the spark gap is enclosed in a glass envelope and the tube is partially evacuated. The arc is formed as large numbers of electrons are conducted through the ionized gas or vapor. There is an optimum pressure that will give the best T-R operation. The recovery time or deionization time of the gap can be reduced by introducing water vapor into the tube rather than air. A T-R tube containing water vapor at a pressure of 1 mm of mercury will recover in $0.5 \mu\text{s}$.

T-R tubes for use at microwave frequencies are built to fit into, and be a part of, the resonant cavity used as a transformer. The high Q of the cavity and the vapor in the evacuated portion of

the tube reduce the power needed to maintain the gap discharge and the power of the transmitted pulse that reaches the receiver. The speed with which the gap breaks down after the magnetron fires can be increased by placing a third electrode within one of the main electrodes of the gap (fig. 8-24A). This electrode is known as a "keep-alive," and has a potential of about -1000 v with respect to the main gap. A glow discharge is maintained by the keep-alive and one electrode of the main gap. This action provides ions for quickly forming an arc across the main gap when the transmitted pulse is applied. The negative voltage of the keep-alive also prevents stray ions from reaching the main gap to produce noises in the receiver.

The life of the T-R tube is determined by two main factors. The first and most common cause of failure is due to the gradual buildup of metal particles that are dislodged from the electrodes of the gap and become spattered on the inside of the glass envelope. These particles act as small, conducting areas and tend to lower the Q of the resonant cavity and to waste power. If the tube is continued in use for too long a period of time, the particles will begin to form a detuning wall within the cavity and will eventually prevent the T-R tube from functioning. The second cause of failure is due to absorption of the gas within the enclosure by the metal electrodes. The result is a gradual reduction of the pressure within the tube to the point where it becomes very difficult to break down the gap. The final result is that extremely strong signals (from the transmitter) are fed to the receiver. Because both causes of failure develop gradually, the T-R tube must be checked carefully and periodically to determine its level of efficiency.

CAVITY T-R SWITCH

The majority of T-R tubes are mounted in cylindrical cavities, with the metal electrodes connected to and forming part of the end walls (fig. 8-25). The cavity is excited in such a manner as to produce a strong electric field across the gap, and therefore to cause an arc with the minimum applied signal. The loop (formed by bending the inner conductor of the coaxial feed line) excites the cavity of figure 8-25. The coupling loop is a low impedance across the coaxial line and therefore current through the loop is large, and a strong magnetic field is

set up. The loop is placed so that it will reinforce the magnetic field within the cavity. The amount of coupling is controlled by rotating the loop around the axis of the inner conductor. Signals that are fed to the receiver are removed from the cavity by a similar loop placed on the opposite side of the gap from the input loop.

A second method of feeding the cavity from a coaxial line is by means of slots that couple the field of the line to that of the cavity (fig. 8-26). The output of the magnetron is matched to a coaxial line, which feeds the transmitted pulse to the antenna. The outer conductor of the coaxial line adjacent to the magnetron is made into a sliding section having a side aperture, or slot, in the center. The slot opens into the resonant cavity of the T-R box on its periphery. Another slot on the opposite side of the cavity is cut through into the receiver coaxial line.

During the transmitted pulse, energy is coupled into the cavity and produces a large voltage across the gap. The gap breaks down, forming an arc that short circuits the center of the cavity. The field built up within the cavity is very weak because the cavity is detuned during the arc, and the net effect is the same as if the input feed-line slot were closed. Because the field is weak, very little energy is coupled into the receiver feed line.

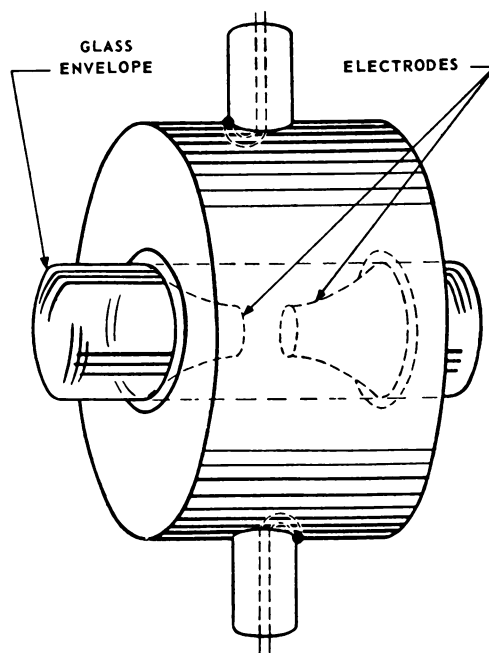


Figure 8-25. —Cavity T-R box.

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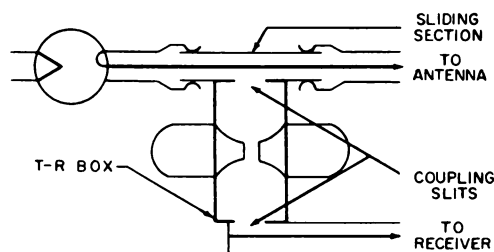


Figure 8-26.—Slot-coupled cavity. 67.27

At the end of the transmitted pulse the magnetron impedance changes, so that received signals see a mismatch at the magnetron and are reflected. The position of the slot into the cavity is adjusted by means of the sliding joint to be placed at a current maximum of the associated coaxial line (fig. 8-27). The large current produces a strong magnetic field, which leaks through the slot into the cavity to reinforce the field of the cavity. The received signals are not strong enough to break down the gap, and the field within the cavity is not affected by the presence of the gap. The slot in the receiver feed line permits some of the field in the cavity to link the inner conductor of the line at a point where the current is a maximum. By selecting the proper size and shape of the slots, the received signals are passed, with very little loss, to the receiver. The position of the antenna feed-line slot can be adjusted to absorb all of the received signal energy from the antenna feed line, and therefore to prevent standing waves between the T-R switch and the antenna.

WAVEGUIDE T-R SWITCH

Resonant-cavity T-R switches are applied to waveguides either directly or indirectly to obtain switching action. The indirect method

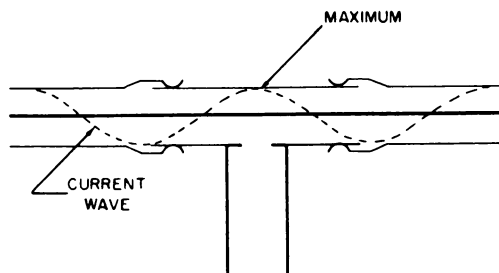


Figure 8-27.—Current wave reflected by magnetron. 67.28

uses a coaxial line T-R system, and then couples the coaxial line into the waveguide that feeds the antenna. If large losses are incurred by the use of a coaxial line, the resonant cavity can be coupled directly to the waveguide. Figure 8-28 illustrates a direct method of cavity T-R switching in a waveguide feed system. The waveguide terminates in the antenna at one end and in a shorting plate at the other. The magnetron uses a voltage probe to excite the waveguide. The transmitted pulse travels up the guide, moving into the T-R box through a slot. The cavity builds up a strong electric field across the gap, breaks it down, and detunes the cavity. This action effectively seals the opening and passes the pulse energy to the antenna.

The signals received during the resting time travel down the guide to the magnetron and the shorting end plate where they are reflected. The slot coupling the waveguide to the cavity is located at a point where the standing-wave magnetic field produced by reflections in the waveguide is a maximum. The maximum magnetic field therefore energizes the cavity. The

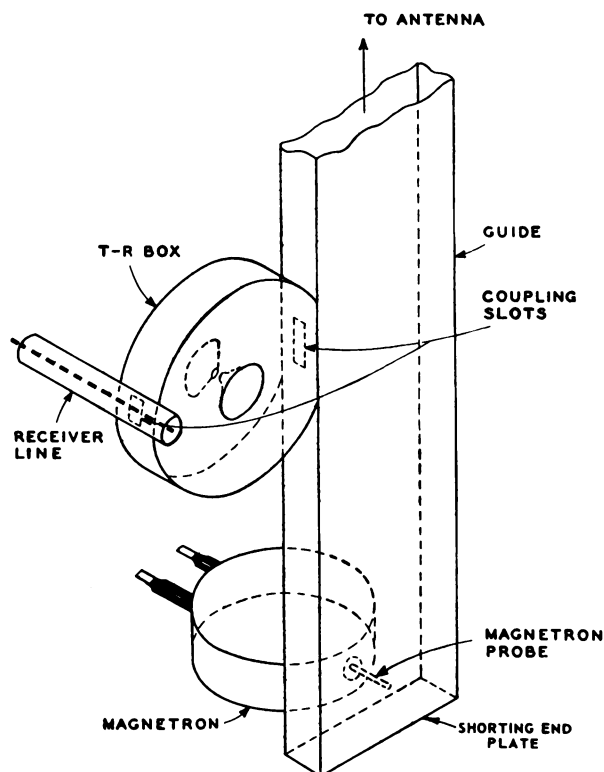


Figure 8-28.—Waveguide using cavity T-R box. 67.29

no signals are not strong enough to cause an arc so that the cavity field is undisturbed by the gap. Thus the cavity field couples into the receiver coaxial line to give maximum energy transfer.

The cavity T-R switch can also be applied to branch lines of the waveguide (fig. 8-29). The magnetron is coupled to the guide by a voltage probe to produce proper excitation. To ensure maximum use of the received signals, an anti-T-R switch is included. The transmitted pulse travels from the magnetron to the anti-T-R branch where part of the energy is diverted into the gap. A slot, S, is placed across the waveguide a half wavelength from the main guide and passes the r-f energy through it into the cavity. The cavity builds up the electric field that breaks down the gap, detunes the cavity and as a result, effectively closes the slot. One half wavelength away this action effectively closes the entrance to the anti-T-R branch and limits the amount of energy entering the anti-T-R branch to a small value.

Most of the energy is therefore directed down the guide to the antenna. On reaching the receiver branch the same effect is produced by the T-R switch in the receiver line. Because the energy entering both openings is effectively

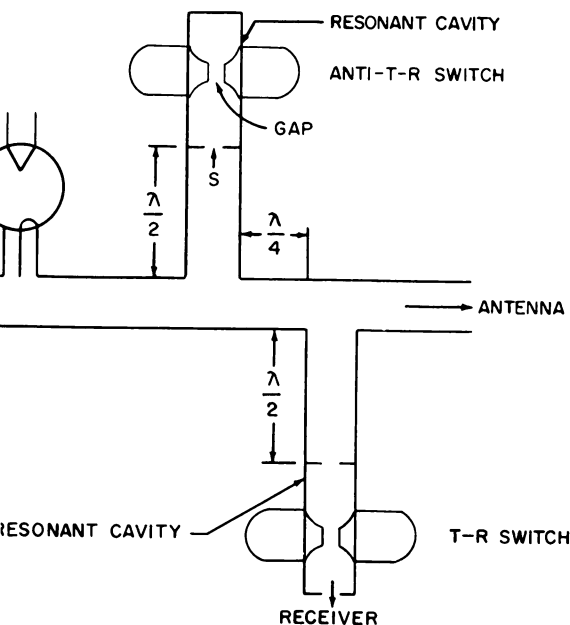


Figure 8-29. —Cavity T-R box applied to branch lines of waveguide.

limited by the gaps, maximum energy is transferred between the magnetron and the antenna.

During the resting time, the anti-T-R spark gap is not broken down by the received signals. The resonant action of the anti-T-R cavity and the standing waves set up in the waveguide caused by the echo signals limit the amount of echo signal energy entering the waveguide leading to the magnetron to a small value so that most of the echo signal enters the receiver branch.

HYBRID JUNCTIONS

Hybrid junctions are used in waveguide applications as balanced mixers, balanced duplexers, and as switches and power splitters. Two common types of hybrid junctions are the MAGIC T and the HYBRID RING, or RAT RACE. Another more recent development is the SHORT-SLOT HYBRID JUNCTION.

Before the magic T and the hybrid ring are discussed in detail, it is desirable to include a simplified explanation of the action of E-type T junctions and H-type T junctions.

T JUNCTIONS

E TYPE—An E-type junction is illustrated in figure 8-30A. The name derives from the fact that the arm (labeled b) extends from the guide in the line of direction of the E field, of the arms, a and c (fig. 8-30B). The reversal of the arrows in arm a with respect to those in arm c indicates a phase reversal of the electric field of 180° . Although they are not shown in the figure, electromagnetic lines always accompany the electrostatic lines. For simplicity, the electromagnetic lines have been omitted.

In figure 8-30B (1), the signal is fed into arm b, and out-of-phase signals are obtained from arms a and c. In part (2), inphase signals are fed into arms a and c, and no output signal is obtained from arm b. In part (3), out-of-phase signals are fed into arms a and c, and an output is obtained from arm b. In part (4), there is one input and two outputs; and the same is true of part (5), except that the signal is fed in a different arm.

H TYPE.—An H-type T junction is illustrated in figure 8-31A. The name derives from the fact that arm b extends from the guide with the longitudinal axis of arm b parallel to the planes of the H (magnetic) lines. For simplification, only the E fields for various inputs are shown

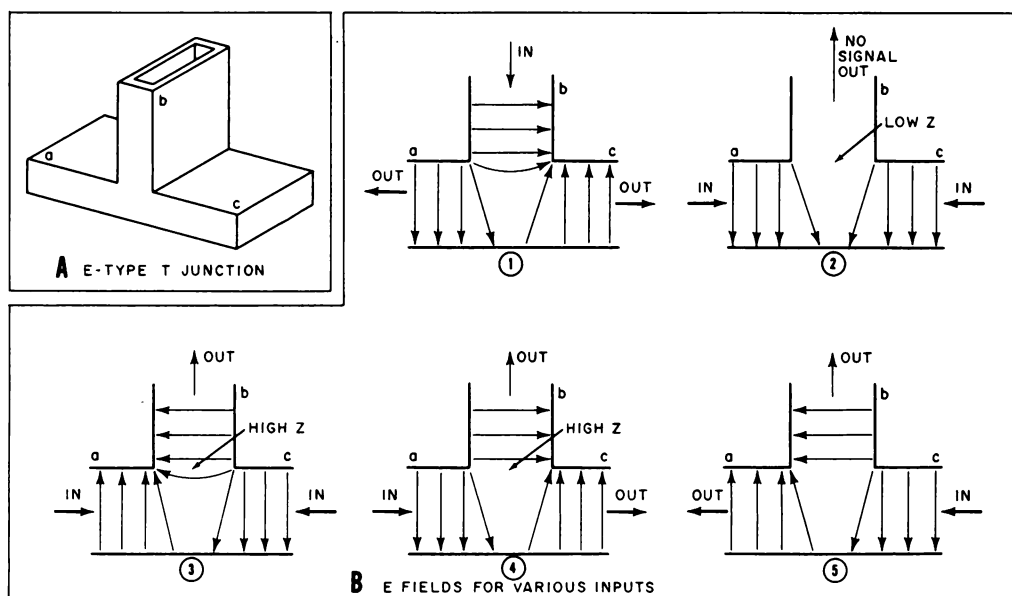


Figure 8-30. — E-type T junction and E fields.

25.180

in the illustrations of part B. In part B, the junction is tilted so that the arm b points down. The plus signs indicate that the direction of the E lines is away from the observer. The dots indicate that the direction of the E lines is toward the observer. A phase shift of 180° occurs as the directions reverse. The lines are crowded in the center of the guide (for the TE_{10} mode) where the field is strongest and less crowded away from the center where the field is weaker. At the boundary surfaces paralleling the E lines, the E field is zero.

In figure 8-31B (1), the signal is fed into arm b, and inphase signals are obtained from arms a and c; and in part (2) inphase signals are fed into arms a and c, and an output signal is obtained from arm b. If out-of-phase signals are fed into arms a and c, as in part (3), no output is obtained from arm b. If, as in part (4), a signal is fed into arm a, an output will be obtained from arms b and c. Similarly if a signal is fed into arm c, an output will be obtained from arms a and b (not shown).

THE MAGIC T

The magic T, a simplified version of which is shown in figure 8-32, is used as a balanced mixer at the input of radar receivers. The echo pulses from the antenna are relatively weak, and noises generated in the local oscillator are balanced out by the action of the magic T. With-

out this action the noises would be of sufficient amplitude to interfere seriously with the signal.

The operation of the magic T may be explained briefly as follows:

1. The output of the klystron local oscillator is fed into the H-plane arm. As indicated in figure 8-31B (1), the oscillator signal will divide into two inphase components, one going into arm a and one going into arm c.

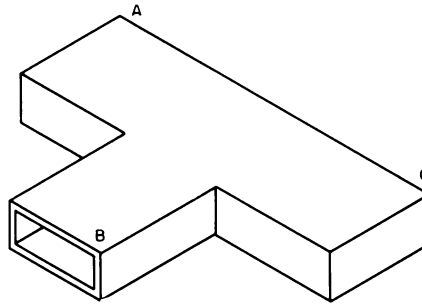
2. The relatively weak echo signal from the antenna is fed into the E-plane arm. As indicated in figure 8-30B (1), this signal will divide into two out-of-phase components that will move into arms a and c.

3. The signal entering the E-plane will not enter the H-plane arm because of the zero potential (satisfying the boundary condition of zero potential at the side of the E-plane arm) existing at the entrance to the H-plane arms. Maximum potential should exist at the entrance if energy is to move down this arm.

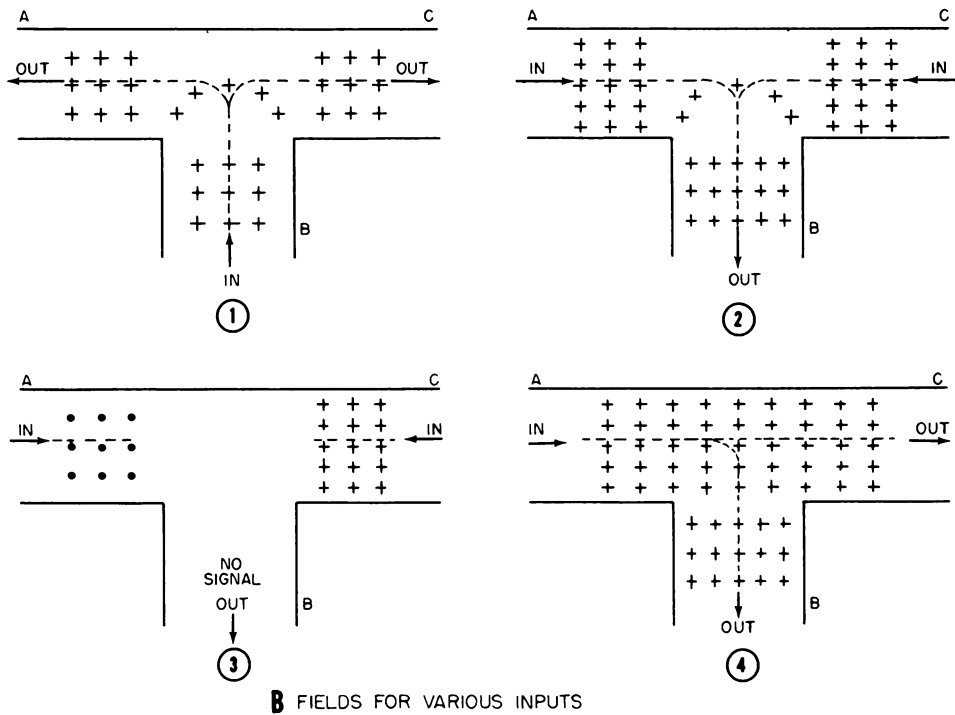
4. The signal entering the H-plane arm will not enter the E-plane arm because there is no potential difference across the input of the E-plane arm.

5. From the H-plane arm, inphase oscillator signals of relatively large amplitude are coupled to the crystal rectifiers, which are correctly positioned in the guide to couple out the energy.

6. However, the rectified inphase signals from the local oscillator are balanced out in the



A H-TYPE T JUNCTION



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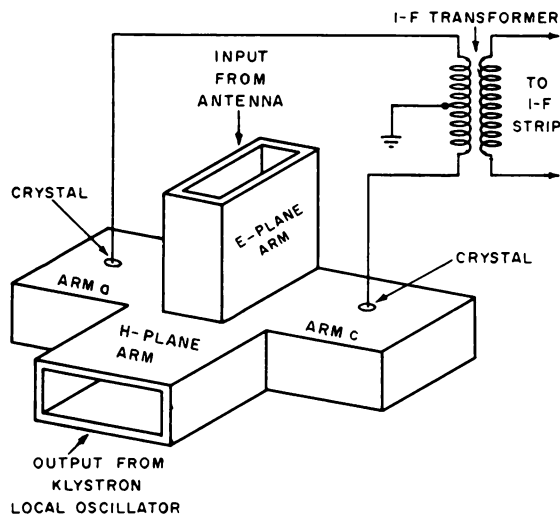
Figure 8-31. —H-type T junction and E fields.

primary of the i-f transformer and do not appear at the output. From the E-plane arm, out-of-phase signals of relatively small amplitude (echo signals) are also coupled to the crystal rectifiers. The rectified echo signal, although properly phased to produce a balanced input to the i-f transformer, will not produce an appreciable output at the secondary because of the low energy contained in the signal and the capacity shunting effect to ground.

7. The crystal rectifiers are nonlinear devices, and the output from each crystal is an

i-f signal equal to the difference between the local-oscillator frequency and the incoming signal frequency. Because of the out-of-phase signals fed from the E-plane arm to the two crystals, the i-f amplitude variations at the outputs of the crystals will be 180° out of phase with each other. This action produces a balanced input at the difference frequency to the i-f transformer.

8. Noise pulses generated in the local oscillator will reach the primary of the i-f transformer in phase, and thus will be balanced out.



67. 31

Figure 8-32. —Balance mixer employing a magic T.

In applications (for example, in mixing circuits) where small amounts of power are involved, the magic T may be used to advantage. However, unless some type of matching device is used, power losses will result. When matching devices are used, the power handling capability is reduced. Therefore the magic T is not used as a duplexer in high-power radar systems.

THE HYBRID RING

The hybrid ring is used principally as a duplexer in a high-power radar system. However, a combination of three hybrid rings may be used as a balanced mixer. This type of mixer is very effective in isolating the receiver from the transmitter during the time the transmitter is firing.

A simplified version of the hybrid ring used as a duplexer is illustrated in figure 8-33A and B. The operation during transmission and reception is illustrated in parts C and D, respectively.

DURING TRANSMISSION (fig. 8-33C) the operation of the hybrid ring may be explained as follows:

1. The field from the transmitter enters arm 3. At the junction with the ring, the field divides into two out-of-phase fields, one moving clockwise around the ring and the other, counterclockwise. (See figure 8-30B (1)). In order that energy may be coupled to the antenna via arm 1, the E fields arriving at the arm 1 junction must be 180° out of phase (fig. 8-30B (3)).

2. The field moving clockwise around the ring from arm 3 fires the T-R tube in arm 4, and the energy is blocked from the receiver or load. A high impedance (equivalent to an open circuit) appears at the junction of arm 4 and the ring. There is a phase reversal at this junction (fig. 8-30B (4)).

3. The field moving counterclockwise from arm 3 "sees" a short circuit at the arm 2 junction when the T-R tube in arm 2 fires, and there is no phase reversal at this junction. The amount of energy entering waveguide 2 is limited by the action of the spark gap (not shown in the figure).

4. If the complete circuits are traced out, it will be seen that the clockwise and counterclockwise signals arriving at the junction of arm 1 are of opposite polarity and will be propagated through the arm to the antenna (fig. 8-30B (3)).

DURING RECEPTION (fig. 8-33D) the operation of the hybrid ring may be explained as follows:

1. The relatively weak signal from the antenna enters arm 1 and divides at the junction into two out-of-phase components (fig. 8-30B (1)). To avoid coupling energy into the transmitter via arm 3, in phase signals must arrive from both directions at this junction (fig. 8-30B (2)).

2. The energy moving clockwise around the ring from arm 1 is not sufficient to fire the T-R tube in arm 2, and energy passes to the receiver through arm 2. There is a phase reversal (guide 2 presents high Z at the junction with the ring, fig. 8-30B (4)), and the remainder of the energy moves clockwise around the ring to arm 3.

3. The energy moving counterclockwise around the ring from arm 1 is likewise not sufficient to fire the T-R tube in arm 4, and energy passes to the receiver through arm 4. There is a phase reversal (fig. 8-30B (4)), and the remainder of the energy moves counterclockwise around the ring to arm 3.

4. At arm 3 the clockwise and counterclockwise components are in phase, and no energy is coupled to the transmitter through arm 3 (fig. 8-30B (2)).

DIRECTIONAL COUPLERS

Directional couplers are used in microwave systems to monitor power that moves in one particular direction along a transmission line

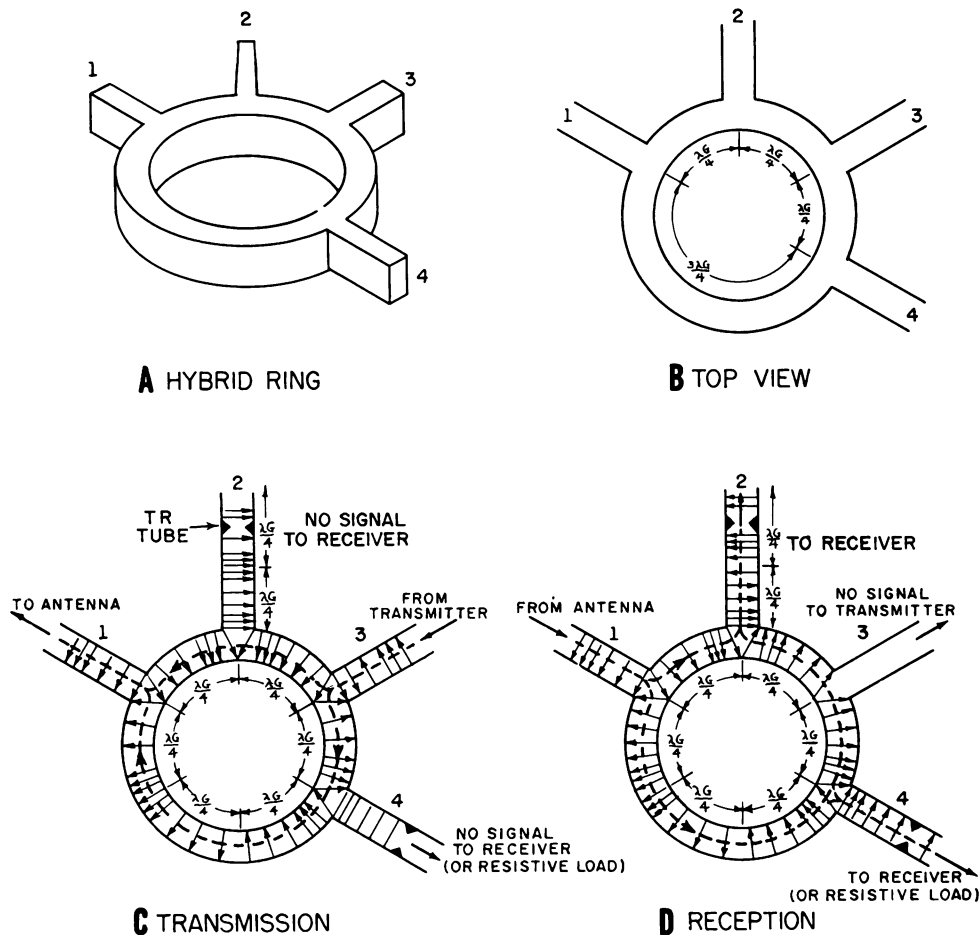


Figure 8-33.—Hybrid ring duplexer showing E lines during the transmission and reception.

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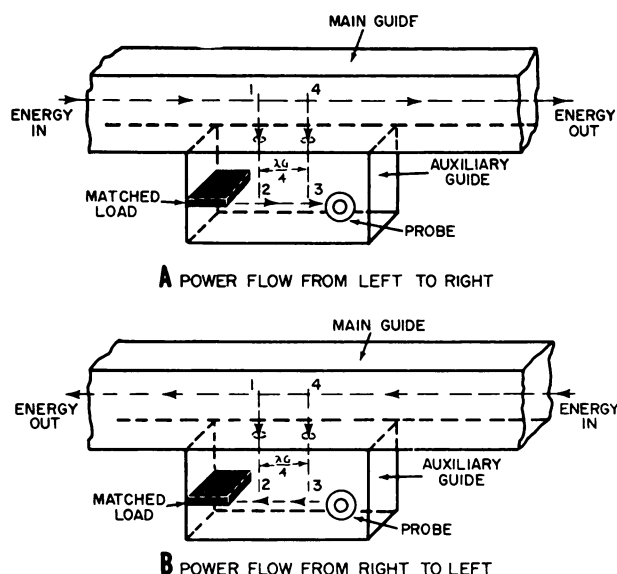
(for example, a coaxial line or a waveguide). The power extracted is only a small portion of the power propagated along the transmission line; however, its magnitude must be proportional to the magnitude of the power propagated along the line. The coupling units are so arranged that reflected signal power does not affect the accuracy of the measurements.

Directional couplers are an integral part of radar systems and are so connected in the transmission line that either the transmitted or the reflected power may be sampled. "One-way" directional couplers will be treated first and then bidirectional couplers will be described. In each case only a simplified analysis is given; a more rigorous treatment may be found in commercial texts.

TWO-HOLE DIRECTIONAL COUPLER

A simplified version of a two-hole directional coupler is illustrated in figure 8-34. A small percentage of the energy flow from left to right is coupled to the probe. However, energy flow from right to left is not coupled to the probe, but is dissipated in the matched load. The action of the coupler may be explained by the use of the figure.

In figure 8-34A, energy is coupled from the primary guide to the secondary guide by the two small holes. Energy that moves to the probe through the path, 1, 2, 3, traverses the same distance as the energy that moves to the probe through the path, 1, 4, 3. These two energy



1.264

Figure 8-34.—Two-hole directional coupler.

components therefore arrive at the probe in phase and may be coupled out to the measuring device.

Energy arriving at the matched load through the path, 1, 4, 3, 2, travels a half wavelength farther than the energy arriving at the matched load through the path, 1, 2. These two energy components arrive out of phase and therefore cancel.

In figure 8-34B, energy moves from right to left. That part of the energy moving through the path, 4, 3, 2, passes through the same distance as the part moving through the path, 4, 1, 2. Therefore, these two energy components arrive in phase at the matched load where they are absorbed.

Energy arriving at the probe through the path, 4, 1, 2, 3, travels a half wavelength farther than the energy arriving at the probe through the path, 4, 3. These two energy components therefore arrive at the probe out of phase and cancel.

BIDIRECTIONAL COUPLER

A simplified diagram of a bidirectional coupler used in a radar system is shown in figure 8-35. The coupler is used to couple a small amount of the r-f power to the echo box. The power coupled out is applied to the echo box to check the system performance.

Energy from the transmitter is fed in at the right-hand end of the main guide, and the echo energy from the target is fed in at the left-hand end of the guide. Some of the transmitted energy is coupled through the coupling holes (between the main guide and the coupler) into the transmitter coupler auxiliary guide. This portion of E_t , labeled E_t' , is about 40 db below $(\frac{1}{10,000})$ of the transmitted energy. It may be coupled out at the transmitter coupler probe. Another portion of the transmitted energy (labeled E_t'') about 25 db below $(\frac{1}{315})$ of E_t enters the receiver coupler. This energy is dissipated in the load. In addition, a very small amount of E_t (approximately 60 db $(\frac{1}{1,000,000})$ of E_t , and labeled E_t''') couples to the receiver coupler probe.

Some of the echo, or received, energy (E_r), labeled E_r' , is coupled to the probe in the receiver coupler. This energy is about 25 db below E_r . A second portion of E_r (labeled E_r'' , and about 40 db below E_r) is coupled to the load in the transmitter coupler. A third portion of E_r (labeled E_r''' , and about 30 db below E_r) is coupled to the probe in the transmitter coupler.

Both the transmit coupler and the receive coupler may be considered to have a certain COUPLING FACTOR and a certain DIRECTIVITY.

The coupling factor determines the proportion of the energy existing in the main guide that is coupled into the auxiliary guide. The orientation of the coupling wave will be coupled to the probe or to the load end of the couplers. The figure shows that energy traveling from right to left in the main guide couples to the probe in the transmitter coupler and to the load in the receiver coupler; it also shows that for a wave traveling from left to right, the received energy couples to the probe in the receiver coupler and to the load in the transmitter coupler.

The directivity of the coupler is a measure of the amount of the unwanted wave that reaches the output probe. The symbols E_t' and E_r' represent unwanted energies in the respective couplers.

BETHE-HOLE COUPLER

A Bethe-hole coupler is shown in figure 8-36. Waves are excited in the auxiliary guide by both the electric and the magnetic field in the

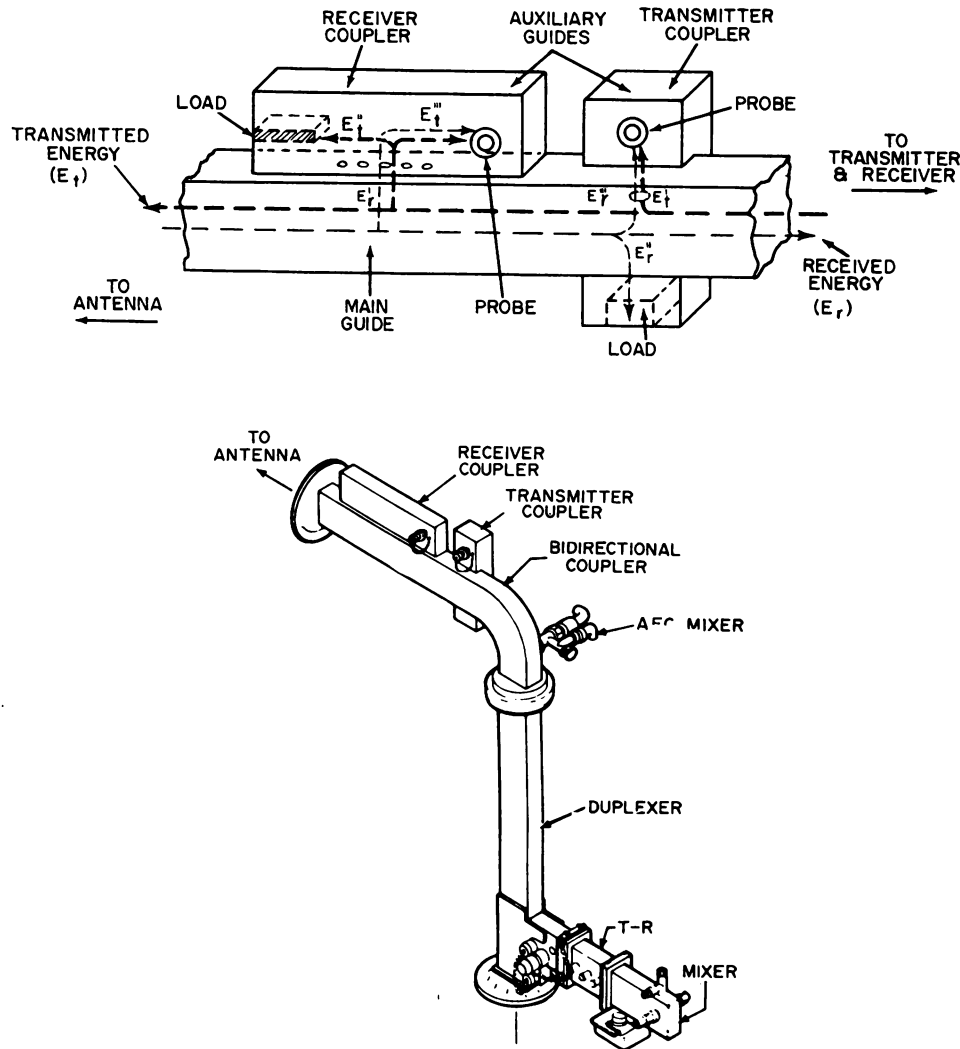


Figure 8-35.—Bidirectional coupler.

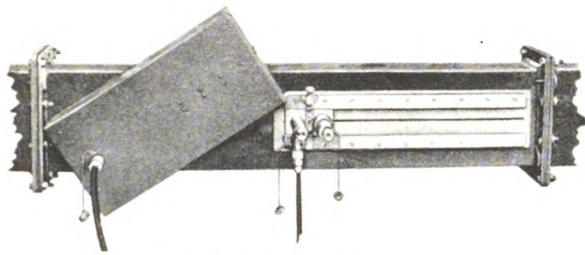
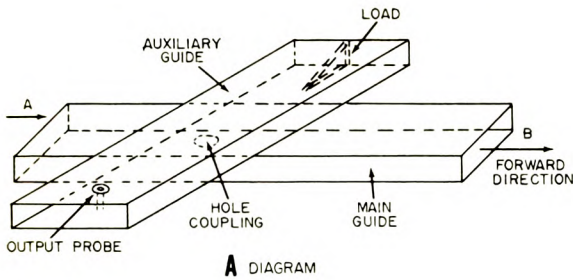
67. 33

main guide. Because of the phase relations involved in coupling the energy through the hole, the waves cancel in the forward direction and reinforce in the reverse direction. That is, energy entering at A is coupled to the probe, but energy entering at B is absorbed in the load. If the two guides were parallel, there would be a greater degree of coupling of the magnetic component than of the electric component, and the directivity would be poor. By placing the auxiliary guide at the proper angle, the magnetic and electric components that are coupled into the auxiliary guide may be made equal and the desired directivity thus obtained.

TYPICAL RADAR R-F SYSTEM

SYSTEM OPERATION

The r-f system consists of three parts: the magnetron, the receiver waveguide section, and the output section. The receiver section is shown in figure 8-37. The receiver waveguide section contains two A-T-R tubes, a T-R tube, a crystal mixer assembly, and a crystal gate motor. The output section contains a directional coupler and a slotted section (fig. 8-38).



67.34

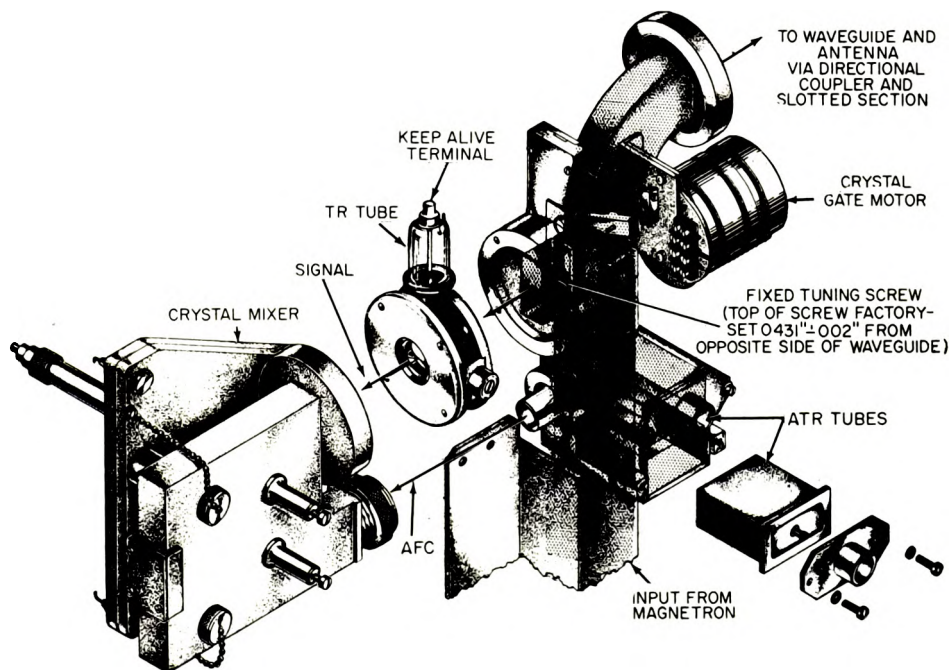
Figure 8-36.—Bethe-hole directional coupler.

When the magnetron oscillates, a pulse of r-f energy is sent to the receiver waveguide. Because the T-R tube is tuned to the magnetron

frequency, the tube fires, and very little of the transmitted energy is permitted to reach the receiver. To ensure rapid ionization, the keep-alive electrode is supplied with -450 v from the receiver; and this potential maintains partial ionization at all times. A small portion of the energy is coupled through an 80-db attenuator to the A-F-C crystal (not shown) and is used for A-F-C operation. Because the A-T-R tubes are broadly resonant over the entire band, both fire during the time of the pulse.

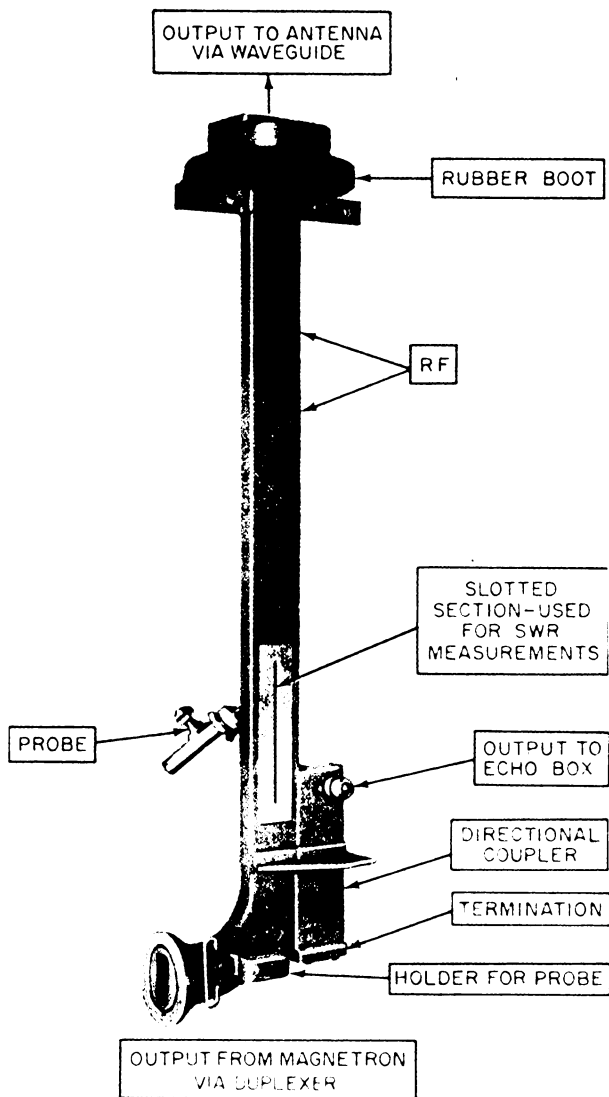
The duplexing cavities have little effect on the transmitted energy, and most of the energy is therefore fed to the output section. The directional coupler can be connected to the echo box to give an indication of transmitted power; but because the directional coupler has an attenuation of 20 db, little power is taken from the waveguide. The output section transmits the r-f energy to the antenna via the flexible waveguide and the waveguide run.

During reception, both A-T-R tubes stop firing and effectively short out that part of the r-f section below the signal mixer. Thus, received echoes are not absorbed by the magnetron but instead are coupled through the T-R tube to the mixer.



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Figure 8-37.—R-F section, exploded.



1. 265
Figure 8-38.—Directional coupler and slotted section.

The A-T-R tubes resemble sealed metal boxes with a window at the waveguide end that arcs across during transmission.

The T-R tube contains its own cavity and is tuned by a movable tuning plug. The movable plug is moved in and out of the cavity by means of a tuning screw, which is connected to the plug through a sealed diaphragm. The keep-alive electrode is brought out to a standard plate cap.

The crystal gate motor operates a shutter in the space between the receiver waveguide and the T-R tube. When the radar is shut down, the shutter is closed and most of the r-f energy

from nearby radars is prevented from reaching the crystal mixer. Because the keep-alive voltage is not applied to the T-R tube when the equipment is on standby, energy from nearby radars might not cause the T-R tube to fire but it still might be large enough to damage the mixer. For further protection, the shutter opens slowly when power is applied. When power is removed from the gate motor, a clutch arrangement immediately closes the shutter and thus provides instantaneous protection.

SIMPLIFIED TWO-WIRE ANALOGY OF R-F SYSTEM

A simplified analogy of the r-f system is illustrated in figure 8-39. Although the analogy is not exact, it may aid in understanding of the actual r-f system.

The waveguide appears as a two-wire balanced line, and the T-R and A-T-R cavities are shown as parallel-resonant circuits with a spark gap across them. The signal mixer is shown as a crystal that is transformer coupled to the T-R tube cavity. The A-F-C crystal mixer is shown coupled to the line through an 80-db attenuator. The directional coupler is shown coupled to both lines through four capacitors. Actually, the directional coupler is a short piece of waveguide with a termination at the lower end and an output probe to the echo box at the upper end. It is coupled to the waveguide through two holes one-quarter wavelength apart in the narrow side of the waveguide.

During transmission the magnetron emits energy, which flows along the line to the right. The A-T-R tubes fire, but (being one-quarter wavelength from the line) they appear practically as an open circuit on the line. The A-F-C mixer picks up a tiny portion of the energy, but the attenuation is so high (80 db) that there is little effect on the main power. As the energy flows up the line, the T-R tube fires and appears across the line as an open circuit. Finally, the directional coupler absorbs a small part of the energy, and the remainder is passed up the waveguide to the antenna, where it is radiated. Because the attenuation of the directional coupler is 20 db, only a small part of the power is absorbed.

Energy flowing from A to G in the directional coupler section travels by two paths, ACG and AEG; and the energy flowing from B to H travels by two similar paths, BDH and BFH. The four paths are each one-half wavelength long and the

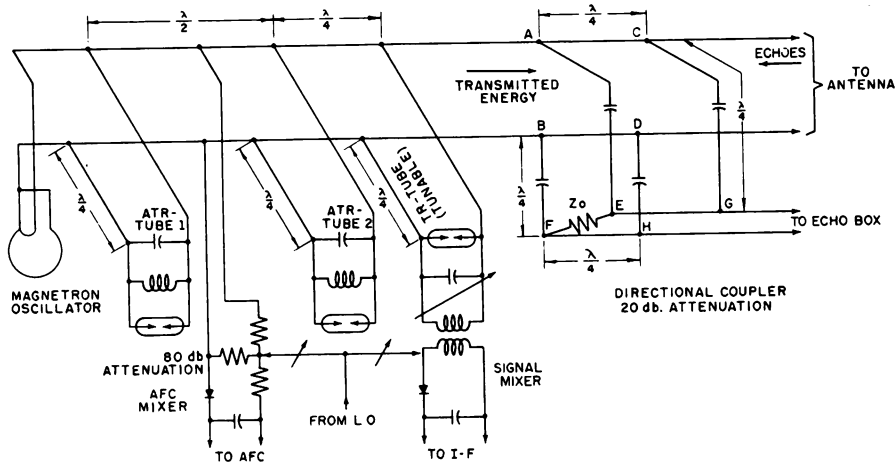


Figure 8-39. —Simplified two-wire analogy of r-f system.

voltage from G to H is proportional to the transmitted energy. (The 20-db attenuation is not shown.)

During reception, the echo energy flows down the line from right to left, and appears first at points C and D. Again, the energy flows from the input points (C and D, in this case) to the same output points in the directional coupler, G and H. However, because the two paths from C to G are (1) CG (one-quarter wavelength) and (2) CAEG (three-quarter wavelength), the energy arrives at G out of phase and is canceled. Similarly, the paths, DH and DBFH, are one-quarter and three-quarter wavelengths respectively, and they cancel out. Thus the directional coupler output for received echoes is zero. Very little

of the received power is absorbed in the directional coupler.

The received energy then travels down the line to the T-R tube, which has ceased to fire. It is coupled through the tube to the signal mixer, and thence to the signal i-f channel. The second A-T-R tube also is not firing, and it appears across the line as a short circuit. The short circuit reflects any received echoes back to the T-R tube, one-quarter wavelength farther up the line. These reflected echoes are in phase with the received energy at the entrance to the T-R tube and they reinforce it. The first A-T-R tube has a similar effect and is located one-half wavelength from the second A-T-R tube. The A-F-C circuit has negligible effect because of its 80-db attenuation.

CHAPTER 9

MICROWAVE COMPONENTS

INTRODUCTION

This chapter deals with the components commonly found in fire control radars and associated equipment using microwave frequencies. Before we discuss these components, however, we will establish the meaning of the term microwave, and explain why special components are necessary at microwave frequencies. On the surface it would appear that the definition of a microwave would be relatively simple, for in the electrical field the prefix micro normally means a millionth part of a unit. But micro also means small, which is a relative term; it is used in this sense here. Thus the best we can do is to define the word microwave as a term loosely applied to electromagnetic waves in the frequency range of approximately 1000 megacycles (mc) per second and upward. Microwave circuits generally use distributed-constant circuits enclosed by the conducting boundaries. In other words, the circuit's constant characteristics of resistance, inductance, and capacitance exist along the entire length or area of the circuit as distinguished from conventional circuits where these characteristics are concentrated in components such as coils, capacitors, and resistors. As an example of inductance distributed along the length of a microwave circuit, a wire 0.040 inch in diameter and 4 inches long may have an inductance of approximately 0.1 microhenry. At 1 mc the ohmic value of the inductive reactance is approximately 0.63 ohms. At 1000 mc it becomes approximately 630 ohms, which will exercise considerable choking effect on the circuit. Obviously the length of this wire would be critical in a microwave circuit. One of the most difficult problems in electronics is amplifying r-f voltages at frequencies above 1000 mc. Fire control radars have frequencies well above 1000 mc due to the many advantages of high frequencies.

ADVANTAGES OF HIGH FREQUENCIES

Perhaps the main reason for using higher frequencies is that it is possible to construct directive antennas of smaller size than when lower frequencies are used. Small directive antennas are an important consideration in ship-board equipment where space and weight are major problems.

Aside from the factors of size and weight, these frequencies are highly applicable to radar equipment, for they produce better target echoes and make possible the detection of smaller targets. In general the higher the frequency, the smaller the target that the radar can detect. A target gives the best echoes when it is about a half wave or some multiple of a radar frequency being transmitted. If the target is much smaller than a half wave, the intensity of pulse that it reflects is low. However, as the operating frequency is increased, the half wave becomes smaller and makes it possible to detect smaller targets.

An overall statement as to an advantage of high frequencies is that the higher frequencies enable the use of smaller microwave components.

LIMITATIONS OF CONVENTIONAL TUBES

The maximum power output of a conventional tube is largely independent of frequency until a certain frequency limit is reached; beyond that limit the power output falls off rapidly. Two main factors limit the output and efficiency of a conventional tube as the frequency is increased.

1. Capacitance and inductance associated with the tube's elements, causing radio-frequency loss.
2. Electron transit time.

Since this discussion serves mainly to show the need for special microwave components, it will be limited to just that.

INTERELECTRODE CAPACITANCES

At low or medium radio frequencies the interelectrode capacitances in an ordinary vacuum tube have reactances which are so large that they do not cause any serious trouble. However, as frequencies increase, the reactance of these capacitances become small enough to materially affect the performance of a circuit. A $1\text{ }\mu\text{f}$ capacitor, for example, has a reactance of 159,000 ohms at 1MC. If this capacitor were the grid to plate capacitance of tube, and the RF voltage between these electrodes were 500 volts, there will be an interelectrode capacitance current flow of $500/159,000$, or 3.15 ma. This amount of current flow will not seriously affect circuit performance. On the other hand, at a frequency of 100 MC the reactance decreases to approximately 1,590 ohms. With the same RF voltage applied it is seen that the current flow is $500/1590$, or 0.315 amperes, an amount which will definitely have an affect on the circuit operation.

A good point to remember is that the higher the frequency or the larger the interelectrode capacitance, the higher the current flow through this capacitance. The interelectrode capacitance between the grid and cathode is in parallel with the signal source, (fig. 9-1). As the frequency of the input signal increases, the effective grid-to-cathode impedance of the tube decreases due

to a decrease in the reactance of the interelectrode capacitance. If the signal frequency is around 100 mc or upward the reactance which shunts the source of a-c grid voltage is very low, and a large amount of power is required to develop the necessary grid driving voltage. Hence high frequency signals are partially short-circuited within the tube.

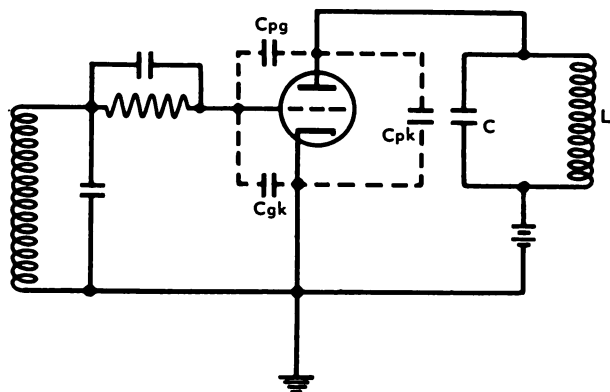
INDUCTANCE OF LEADS

Another frequency limiting factor is the inductance of the leads to each tube element. Since the lead inductances within a tube are effectively in parallel with the interelectrode capacitance, their effect is to raise the frequency limit. But the inductance of the cathode lead is common to the grid and plate circuits, so that it provides degenerative feedback which reduces the tube's efficiency.

TRANSIT TIME PROBLEM

Transit time is the time required for electrons to travel from cathode to plate. In low-frequency operation it is usually taken for granted that electrons leaving the cathode reach the plate instantaneously. No harm is done by this assumption, so long as the electrons' time of flight between the cathode and plate is negligible when compared to the duration of one cycle of the grid signal. At high frequencies, transit time becomes an appreciable portion of a cycle. For example, a transit time of 0.001 microsecond, which is not unusual in radio receivers, is only 0.001 cycle at a frequency of 1 mc. The same transit time becomes equal to the time for an entire cycle at 1000 mc. Transit time depends on electrode spacing and voltage potentials. At transit times longer than 0.1 cycle the tube's efficiency drops considerably. This decrease in efficiency is caused, in part, by a shift in phase between plate current and grid voltage.

If the tube is to operate efficiently, its plate current should be in phase with its grid voltage and 180° out of phase with the plate voltage. In other words, as the grid voltage swings in a positive direction, plate current must increase and plate voltage must decrease in synchronism with the grid signal. In a conventional tube the grid signal intensity modulates the plate current. As the grid signal increases electron flow increases until plate current intensity satisfies the signal and the changed conditions in the tube. When transit time becomes an appreciable



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Figure 9-1.—Effect at interelectrode capacitance on frequency of tuned-plate tuned-grid oscillator.

fraction of a cycle this phase relationship between the tube elements does not hold true. A positive swing of a high-frequency grid signal causes electrons to leave the cathode and flow to the plate. Initially, this current is in phase with the grid voltage. Since transit time is equal to an appreciable part of a cycle, the current arriving at the plate is out of phase with the grid voltage. Transit time effects cause the plate current to lag the grid voltage, and the tube's transconductance has a lagging phase angle. As a result the tubes' power output decreases and plate dissipation increases.

INDUCED GRID CURRENT

The electrons which form the plate current electrostatically induce potentials in the grid as they move past it. As an electron approaches the grid it repels an electron in the grid material out of its orbit. This action leaves a hole in an atom of the grid, and this atom has a positive charge. As the electron recedes from the grid its influence on the grid diminishes and an electron in the grid material is attracted to fill the hole. The electrostatic induction in the grid results in induced currents which consist of a movement of positive charges back and forth in the grid structure. This process is similar to hole current in transistor theory. At low frequencies, where transit time is negligible, the number of electrons approaching the grid is the same as the number of electrons going away from the grid. The current induced on one side of the grid by the approaching electrons is equal to that induced on the other side of the grid by the receding electrons. Since these currents are in opposite directions the combined effect is zero.

When the transit time is an appreciable part of a cycle, the number of electrons approaching the grid is not equal at all times to the number going away. As a result the electrostatically induced currents do not cancel. The effect of this current is to produce, in the grid itself, a loss which may be considered as a loss in an imaginary input resistor connected between grid and cathode. The resistance of this imaginary resistor decreases rapidly as the frequency rises. At ultrahigh frequencies (UHF) this resistance may become so low that the grid is practically short-circuited to the cathode, preventing proper operation of the tube.

RADIO-FREQUENCY CIRCUIT LOSSES:

As the frequency at which the tube operates is raised, the radio-frequency circuit losses increase because of—

1. Increased skin effect.
2. Eddy current loss.
3. Dielectric loss.
4. Energy loss due to direct radiation.
5. Greater capacitance-charging currents.

These factors and their variations with frequency are covered in Basic Electricity, NavPers 10086-A and Basic Electronics, NavPers 10087-A.

REDUCING TUBE LIMITATIONS

The amount of interelectrode capacitance, the effect of electron transit time, and other objectionable features can be minimized in several ways. The most suitable conventional tubes for high-frequency operation have low interelectrode capacitance, close spacing of the electrodes to reduce transit time, a high amplification factor, and a fairly low plate resistance. Since some of these requirements are conflicting, a happy medium must be selected.

There are several ways to reduce the effect of interelectrode capacitance in vacuum tubes. One is to move the electrodes farther apart. However, this is hardly desirable for it increases the transit time. Another method is to reduce the size of the tube and electrodes. This is satisfactory except for one ill effect. It decreases the power handling ability of the tube. Another method is to separate the leads and to bring them out of the envelope at the nearest point. This results in a slight decrease in the capacitances.

Similarly there are several ways to reduce the inductances of the leads. As just mentioned, bringing out electrode leads through the envelope at the nearest point produces a slight decrease in the electrode capacitance in a tube. This also decreases the inductances of the leads. Another method is to make double connections to the electrode. This makes two parallel inductances which cut the lead inductance in half. Another method is to arrange the leads as extensions of the external transmission lines which are the resonant elements of the circuit. Thus the interelectrode capacitances and lead inductances are incorporated as part of the tuned circuit.

It is possible to minimize the inefficiency due to feedback by using a tube that has two separate external cathode connections. When one cathode lead is used for the grid return and the other for the plate circuit the unwanted feedback is prevented, since the grid and plate currents do not flow in a common lead.

For reducing transit time, closer spacing of the electrodes and higher plate voltage are employed. Closer spacing of electrodes, however, causes higher interelectrode capacitances. Therefore, it can be used only when the electrodes are made smaller. For this reason UHF tubes operate at very high plate voltage. Operating with high voltage does, however, necessitate some precautionary measures, such as separating the leads to avoid the presence of excessive voltage gradients in or on the surface of the glass envelope, and avoiding sharp projections on the high-voltage leads or electrodes to prevent arcing.

TRAVELING-WAVE TUBES

In conventional tubes the input signal is coupled from the grid circuit to the plate circuit by the grid's modulation of plate current. Since nothing in nature happens instantaneously, the tube's reaction to the grid signal takes time. As we have pointed out, the conventional tube has serious limitations at high frequencies. Therefore, until recently in radar receivers it has been necessary to heterodyne the r-f return with a signal from a local oscillator and depend on increased i-f amplification to get results. The intermediate frequency is critical. A drift of the intermediate frequency out of the band pass of the i-f amplifier results in a severe loss of amplification. Thus in radars with superheterodyne receivers the i-f amplifiers have a wide bandwidth. But this presents another problem; an increase in bandwidth causes a corresponding increase in noise generated in the amplifier, and a loss in the amplifier's gain. Consequently, weak r-f returns may be lost. High-power, wide-band, microwave amplifiers with a low signal-to-noise ratio would reduce this problem considerably. Velocity-modulated tubes, which are capable of directly amplifying the r-f return, seem to be the answer. The operation of this type of tube depends upon the modulation or change in the speed of electrons passing through it rather than change in plate

current as in conventional tubes. Velocity-modulated tubes offer one of the best possibilities as amplifiers and oscillators at microwave frequencies. Traveling-wave tubes (TWT) are velocity-modulated tubes. In TWTs an electron beam interacts with an electromagnetic wave in such a manner that energy is transferred from the beam to the wave. This interaction causes a large power gain in the wave.

Before we discuss TWTs, we will give some background information. The theory of operation can be more easily understood if we first consider a single electron in motion. The amount of kinetic energy possessed by this electron is equal to half its mass times its velocity squared ($E_k = \frac{1}{2} mv^2$). Thus if electron velocity increases, its kinetic energy increases. An electron in motion creates an electric field and a magnetic field. These fields contain energy proportional to the kinetic energy of the electron which supports them. Therefore if the velocity of the electron decreases, its fields contract and give up energy.

In a velocity-modulated tube a beam of electrons is the source from which the signal to be amplified extracts power. The signal is introduced in such a manner as to interact with the electrons in the beam and vary their velocity. The signal is a sine wave which establishes electrical potentials in the electron beam's path. These potentials produce fields—areas of influence—which vary the transit time of the electrons between the areas. As the signal alternates, the areas alternately assist (accelerate) and hinder (decelerate) the passage of the electrons through the tube. When the signal accelerates the electrons, energy is transferred from the signal to the electron beam. When the signal decelerates the electrons, energy is transferred from the electron beam to the signal. The transfer is accomplished through the electromagnetic fields established by the electron beam and the signal. There is no physical connection between the two circuits. Energy transferred in this manner is covered by Lenz's law which states: "The induced EMF in any circuit is always in such a direction as to oppose the effect that produces it." The amount of energy lost in one circuit is equal to the amount gained in the other circuit.

Initially, the electron density of the beam is uniform. Thus an equal number of electrons are affected by each alternation of the signal's first cycle, and hence the number of electrons accelerated is equal to the number decelerated.

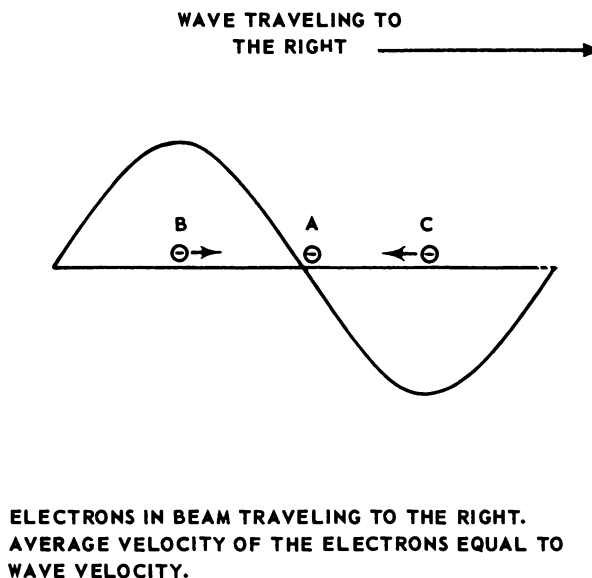
The overall result is that the average velocity of the electrons is not changed after the first complete cycle of the signal, nor is there a net transfer of energy between the signal and the beam. But the signal causes the electrons to form bunches in the beam, and the electron density of the beam is no longer uniform.

Amplification in velocity-modulated tubes depends on electron bunching. The manner in which the electrons are bunched can be understood by considering the motion of individual electrons. Figure 9-2 shows the first cycle of a wave which is moving at a definite velocity to the right. Electron A's velocity is equal to the wave's velocity. Being at the position of zero potential, A is unaffected by the wave. Electron B is accelerated by the positive potential and moves closer to electron A. Electron C is retarded by the negative potential, and electrons A and B tend to catch up to C. Therefore the electron beam, after the first interaction of the signal wave, consists of bunches of electrons separated by regions in which there are few electrons. The bunches are spaced in proportion to the frequency of the signal.

The electron beam is now arranged so that the signal may be amplified. The signal phase velocity with respect to the beam velocity is such that the negative alternation of the signal

occurs when the bunched electrons are in its field of influence. This alternation slows down the electron bunch and energy is absorbed by the signal. On the positive alternation only a few electrons are present in the field. This alternation increases the speed of the electrons, and energy is extracted from the signal. Due to the bunching of electrons the signal absorbs more energy than it gives up. As the signal wave and the electron stream travel through the tube their interaction continues. Each time the signal acts on the electrons the bunching reaction continues. This in turn results in a larger amplification of the signal. The importance of the relationship between the velocities of the signal's traveling wave and the electron beam has not been explained. This will be covered in the discussion of the tube's construction. Notice that a velocity-modulated tube using a traveling wave signal does not use tuned circuits, such as a cavity, or lumped-constant circuits. Hence the tube has a large bandwidth which is limited only by the variations in the traveling wave signal, electron beam velocity, and signal-coupling structures. Later on in our discussion of the klystron we will see that it, too, is a velocity-modulated tube; but its bandwidth is restricted by tuned cavities.

CONSTRUCTION OF TRAVELING-WAVE TUBE



A schematic illustration of a typical TWT is shown in figure 9-3. At the left is an electron gun, similar to the type used in cathode-ray tubes, which produces a beam of electrons. The anode accelerates the electrons and allows the majority to pass through and to move along the axis of the tube toward the collector. The permanent magnets create an axial magnetic field which focuses the electron beam down the center of the tube to the collector on the farther end. The tendency of the electrons to disperse out of the beam is counteracted by the magnetic field. The helix is a helical wound wire (coiled as in an r-f choke), which furnishes a low-impedance transmission line for the r-f energy within the tube. The r-f input and output are coupled onto the helix by directional couplers. The couplers are outside the vacuum envelope of the tube. There is no physical connection between the couplers and the helix. If the r-f energy is in coaxial cables, the couplers are wound in a helical manner similar to the

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Figure 9-2.—Bunching of electrons in a beam.

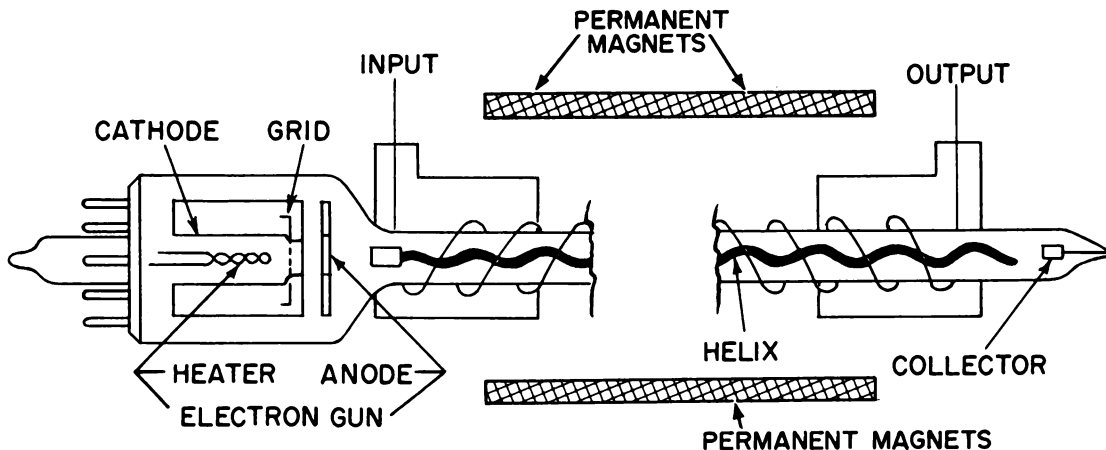


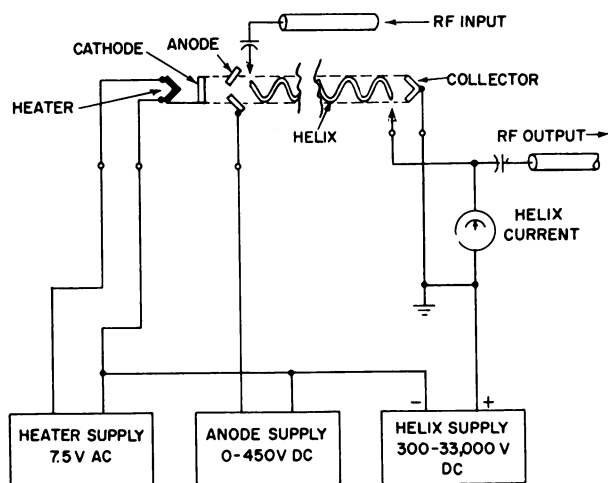
Figure 9-3.—Schematic illustration of a traveling-wave tube.

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helix, except that the direction of the coupler's turns are opposite to those of the tube's helix. If the r-f energy is in wave guides the number of turns of the tube's helix is greater in the coupling areas. The attenuator prevents reflected waves of the output from adding energy to the r-f input.

TRAVELING-WAVE TUBE CIRCUITS

The schematic diagram of the tube circuit is shown in figure 9-4. The power supplies associated with the tube are conventional. Note, however, that the helix is highly positive with respect to the cathode.



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Figure 9-4.—Circuits of a traveling-wave tube.

FUNCTION OF THE HELIX

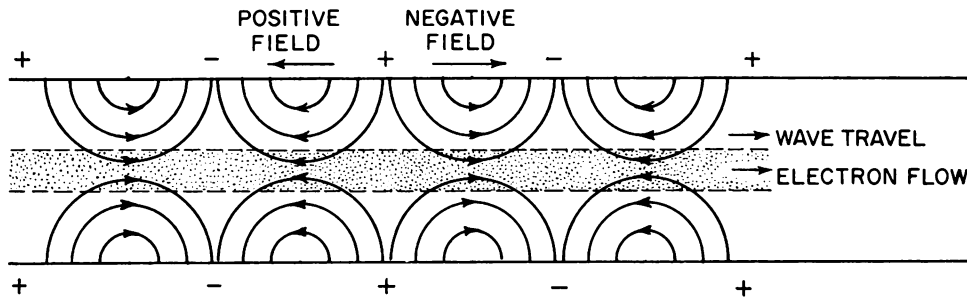
For the electrons to impart energy to the r-f traveling wave, their speeds must be approximately equal. Actually the speed of the electron beam is slightly greater. The function of the helix is to slow down the traveling wave to slightly less than the speed of the electrons. The r-f energy essentially travels at the speed of light along the wire of the helix. But since the wire and the energy follow a helical path, the progress of the energy along the axis of the tube is at some fraction of the velocity of light. The axial velocity of the r-f energy is determined by the dimensions of the turns of wire which form the helix, and by the dielectric loading of the helix. The dimensions referred to are the pitch of the turns, which governs the number of turns per inch, and the circumference of the turns. The helix may slow down the speed of the traveling wave by a factor of as much as 30. The fields associated with this "slow wave" extend outward and inward into the regions adjacent to the helix. It is into the inner region that electrons are sent to interact with the wave. The wave has both magnetic and electric field components. The magnetic component is not useful, but tends to scatter the electrons in the beam. To counteract this effect a magnetic focusing field is established around the tube. The field is created by permanent magnets spaced along the length of the tube as shown in figure 9-3, or by a long thin solenoid.

FUNCTION OF THE ELECTRIC FIELD

The electric field component of the traveling wave interacts with the electron beam, (fig. 9-5). The arrows indicate the direction

the electrons progress down the tube. The electrons become packed into tighter and tighter bunches.

As mentioned before, to obtain amplification the electrons' average velocity must be slightly



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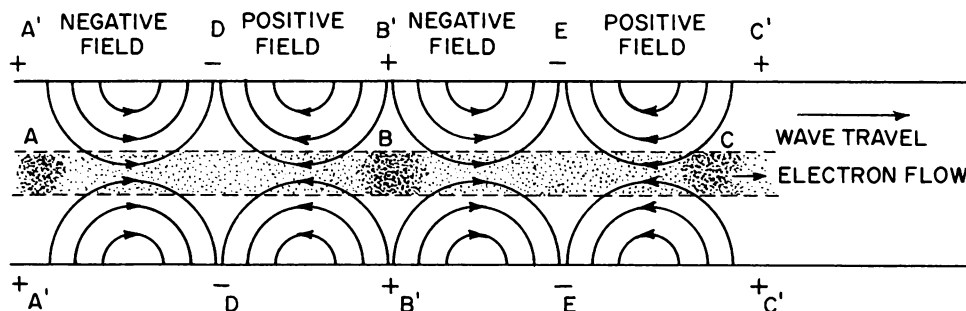
Figure 9-5.—Electric field pattern of a traveling wave.

in which the field will accelerate positive charges. Electrons will be accelerated in the opposite direction. Some electrons will be accelerated and some will be slowed down under the influence of the traveling wave.

The electron beam will alternately be made more or less dense as shown in figure 9-6. Electrons are speeded up as they approach a more positive area and slowed down as they approach a more negative area. Arrows pointing to the left accelerate electrons and represent a positive field. Arrows pointing to the right slow down electrons and represent a negative field. As the electrons and the wave move to the right, electron bunching occurs. This interaction continues as the traveling wave and

greater than the traveling wave's phase velocity. This is known as "synchronous velocity." The average velocity of the electrons is determined by the potential difference between the helix/collector and the cathode of the gun. This is set to obtain synchronous velocity. If the r-f energy changes frequency so as to change the slow wave's phase velocity, the potential difference is varied accordingly. At synchronous velocity the bunched electrons always appear in a retarding field, (arrows pointing to the right in figure 9-6).

When an electron is slowed down, it gives up some of its kinetic energy to the traveling wave that slowed it down. As you know, the opposite is true when the wave causes an



67.44

Figure 9-6.—Electron bunching in beam (electron velocity higher than traveling wave).

electron to speed up. But due to electron bunching more energy is absorbed by the wave than is extracted from it. Hence the amplitude of the wave grows. The wave is sometimes referred to as a "growing wave." As the wave grows, its fields increase in strength. This in turn causes more bunching of the electrons, and greater amplification of the wave. The electrons, after passing through the tube, are drawn off by the collector.

GAIN OF THE TRAVELING-WAVE TUBE

The gain of the tube is determined by the tube's length and the power available in the electron beam. The helix's length measured with respect to the signal's wavelength determines the number of points where interaction between the signal wave and the electron beam will occur. The larger the number of interactions, the greater the amplification. The distance one wavelength covers is a function of signal frequency. Hence there is a relationship between signal frequency and gain. But since the tube does not use tuned circuits, the dropoff of gain due to signal frequency variations is not sharp. TWTs have been designed for frequencies from 100mc to 50,000 mc, and with bandwidths as wide as 7000 mc. Remember, synchronous velocity can be maintained, within reasonable limits, by changes in the potential difference between the helix and the cathode. As the signal frequency increases, however, the number of reactions increases. At each reaction the electron bunch is slowed down. There comes a point where electron speed cannot be maintained above the wave speed. Then the frequency limit of the tube has been reached. To increase the frequency limit, more power must be made available to the electron beam. High power handling requires larger tubes. The physical size of TWTs varies with power and frequency requirements, both of which affect the tube's gain. Some TWTs are designed to have a narrow bandwidth. In these tubes there is a sharp decline in gain with changing frequency.

The power available in the electron beam is furnished by the electron gun. The grid in the gun can be used to turn the electron beam on or off or to modulate the beam. Hence the grid controls electron density, and thus the beam's ability to transfer energy to the traveling wave. The grid bias may be used to amplitude-modulate the tube's output.

FUNCTION OF THE ATTENUATOR

A reflected wave from the output may set up oscillations within the tube by adding energy to the input (positive feedback). This occurs in backward wave oscillators (carcinotrons, described later). This is prevented in TWTs by the attenuator. The attenuator is located on the helix at a point where it will offer maximum impedance to the reflected wave and minimum attenuation to the forward wave.

TWTs are used as continuous-wave power amplifiers, high-power pulse amplifiers, frequency multipliers, mixers, and electronically tunable amplifiers and oscillators. They are capable of amplitude, phase, and pulse modulation.

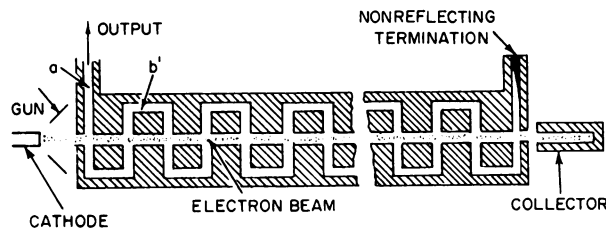
BACKWARD WAVE OSCILLATOR (CARCINOTRON)

The backward wave oscillator or, as it is sometimes called, the carcinotron, resembles the TWT. As mentioned in the description of TWTs, a reflected wave from the output end of the tube travels back towards the gun end. This wave is attenuated to prevent oscillations. The carcinotron is a development that grew out of the traveling wave concept and is inherently an oscillator. This discussion will be based on the operation of the O-type carcinotron. The M-type carcinotron requires a transverse magnetic field and resembles a magnetron type traveling wave amplifier. This type will be covered later in the chapter.

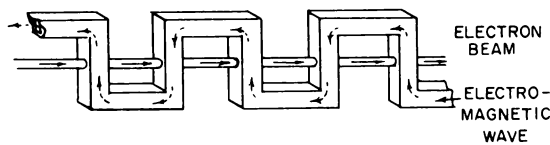
OPERATION

In the backward wave oscillator (fig. 9-7) sustained oscillations depend on the exchange of energy between a stream of bunched electrons moving in one direction and a traveling wave moving in the opposite direction.

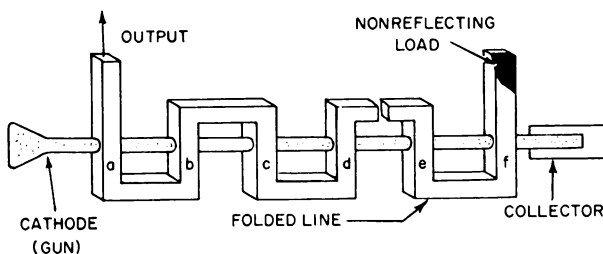
In the tube a structure similar to a folded waveguide crisscrosses the tube axis. The folded waveguide slows down the axial velocity of a traveling wave. An electron beam generated by a conventional electron gun is directed along the tube axis through holes in the waveguide. At each of these holes the traveling wave and the electron beam interact. Thus in the backward wave oscillator the interaction between the wave and the beam is periodic. The time intervals between these interactions is determined by



A CROSS SECTION



B ISOMETRIC VIEW



C COMBINED VIEW

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Figure 9-7.—Schematic diagram of backward wave oscillator (carcinotron oscillator).

electron beam velocity and the distance between the holes. When the electron beam passes through the holes, the electrons are acted upon by the field across the successive holes in the guide, and bunching occurs in the electron beam. Very little energy is required to bunch the electrons, because the energy extracted from the wave to accelerate the electrons is returned to the wave when they are slowed down.

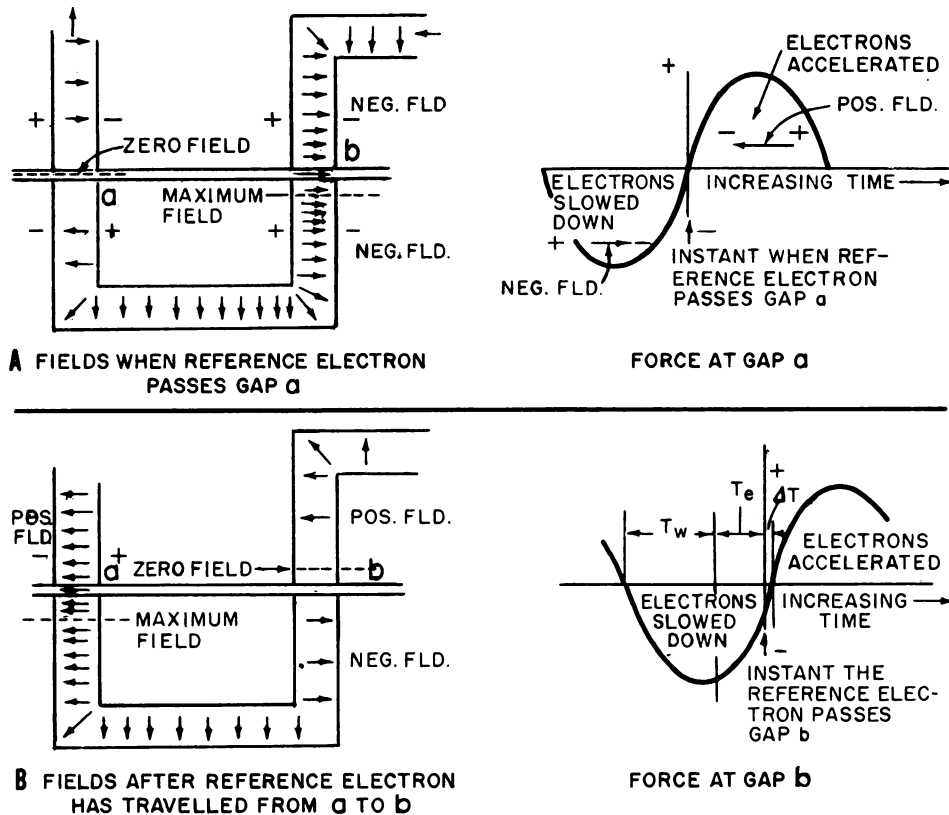
There is no signal input to the tube, and the collector end is terminated in a matched load. Electron bunching is started by noise generating a wave in the guide. The initial wave is

sustained and modulated by interactions with the beam. When the bunched electrons of the beam pass through the successive gaps in the guide they induce fields across the gaps. The fields have a phase velocity equal to the speed of the electron beam. The induced fields move away from the gaps in both directions down the folded waveguide. Those fields moving to right are weakened because components induced at successive gaps are out of phase and cancel. Those fields moving to the left are strengthened because the components induced at successive gaps are in phase and add. These effects are a result of the dimensions of the waveguide's folds and the wave's phase velocity.

BUNCHING ACTION

Bunching occurs as the electron beam passes through the gaps in the waveguide. The electron beam travels toward the collector at a velocity determined by the collector's potential. The traveling wave, which is a result of the fields created by the beam passing through the gaps, has a phase velocity equal to the beam velocity. The wave travels toward the gun end of the tube, but not directly down the tube's axis, for it must follow the path of the guide line. Therefore the axial velocity of the wave through the tube is slightly less than that of the beam. The wave's axial progress is determined by the dimensions of the waveguide's folds and its phase velocity. With these facts accepted, we can use a single electron as a reference and see the bunching action of the tube.

In figure 9-8A and B, the reference electron is traveling from left to right—that is, from gap a to gap b. As the electron passes through gap a, the field in the guide is zero. Thus the electron's velocity is not changed as it passes through the gap. The electron travels on to gap b while the wave travels from gap b to gap a. Since the electron's path is shorter than that of the wave, it arrives at gap b when the field at the gap is negative. You can see this by comparing the time required for an electron to travel between the gaps with the time required for the zero phase of the wave to travel between gaps. The difference in the distances traveled causes the electrons to advance on the phase and arrive at gap b when the field is negative. The negative field slows down the electrons, and the bunching action around the reference electron has started. The velocity-modulation of the electrons is such



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Figure 9-8.—Relationship of field and electrons in the folded-line backward-wave tube.

that the accelerated electrons catch up to the unmodulated electron, and this group joins the retarded electrons to form an electron bunch. This bunch continues to advance on the phase of the wave, encountering decelerating fields of increasing strength at each gap. Hence the electron bunch becomes tighter and tighter as it progresses down the tube. At the collector end of the tube, the total phase advance is approximately a half cycle. As the negative fields in the gap slow down the electron bunch, energy is transferred from the electron beam to the backward wave at each gap. The wave increases in amplitude as it travels toward the gun end of the tube. At the same time, bunching becomes denser as the electrons pass successive gaps in their travel toward the collector. Thus the carcinotron has a built-in positive feedback mechanism; energy transferred to the wave by

the interactions is used in turn to create more interactions.

The phase velocity of the backward wave is determined by the dimensions of the folded waveguide, and the electron transit time between the gaps. The waveguide dimensions are constant for any given tube. Consequently the frequency of the backward wave which is the tube's output is controlled by electron transit time. Transit time is a function of electron velocity, which is controlled by the collector's potential. As a result the carcinotron's output frequency can be changed by varying the collector voltage. This is a definite advantage.

A permanent magnet or a solenoid creates an axial magnetic field to focus the electron beam in the tube. This is identical to the focusing action in the TWT. The BACKWARD WAVE OSCILLATOR (BWO) has a narrow bandwidth due

to the constant distance between the gaps. This fixed distance is comparable with the cavity resonators used in klystrons—the next tubetype to be discussed.

KLYSTRONS

In the FT2 course you were introduced to klystrons. In this discussion we will cover the theory of operation and the functions of this type of tube in detail. Klystrons are velocity-modulated tubes. They are used in radars as oscillators, amplifiers, and mixers at microwave frequencies. Klystrons make use of the transit time effect by varying the velocity of an electron stream within the tube. Traveling-wave tubes use the same principle. But the interaction between the electron beam and the signal takes place over very short distances in klystrons. To obtain efficient interaction between the beam and the signal over these short distances, strong electric fields are necessary. These fields are developed in the klystron by sharply resonant, high-impedance tuned circuits (usually resonant cavities.) Due to the tuned circuits, klystrons have a relatively narrow bandwidth (normally several megacycles), compared to the bandwidth of TWTs. The frequency output of the klystron can be changed by adjusting the tuned circuit (cavity dimensions) or the electron transit time of the tube.

Klystrons can be divided into two broad groups: (1) multicavity klystrons which are used as microwave amplifiers and mixers, and (2) reflex klystrons which have a single cavity and are used as microwave oscillators. Since the operation of both groups depends on velocity modulation, the groundwork for the basic theory has been prepared by our discussion of TWTs. However, we must consider the tuned circuit acting on the electron beam for very short intervals of time and distance.

MULTICAVIDITY KLYSTRONS

Until recently, FC radars were conventional pulse type radars. In this type of radar the high-powered r-f energy is generated by a magnetron working with a modulator. The modulator produces a high voltage pulse to trigger the magnetron. The magnetron generates a short burst of r-f energy, then shuts down operation to wait for the next pulse. Because the magnetron operates intermittently,

there is a big difference between average power and peak power, as defined by the formula.

$$\text{Average power} = \frac{\text{radar pulse width} \times \text{pulse repetition rate}}{\text{peak power}}$$

In continuous-wave radars, average and peak power figures are identical, while in pulse doppler radars the figures are nearly the same. Consequently, to maintain high average and peak power figures, multicavity klystrons have replaced the magnetron in some radars as the generator of the transmitted r-f energy.

Another reason for the use of klystrons, and perhaps the most important, is their frequency stability. Magnetrons are inclined to stray from their proper frequency even under ideal conditions. In conventional pulse radars the frequency drift of the magnetron is compensated for by automatic-frequency-control circuits in the receiver. These circuits adjust the frequency output of the local oscillator, which is normally a reflex klystron, so that the intermediate frequency remains within the designed bandpass. Since both the production and the ultimate use of the r-f energy are located within the radar, the magnetron's frequency drift can be compensated for in this manner. If, however, the radar's r-f energy is used by an external receiver, such as a receiver in a missile, this is not true. In radar receivers that have a narrow bandwidth for clutter rejection the i-f and hence the r-f frequencies are critical.

Basic Theory

We will start with a two-cavity klystron. This type is used primarily as an amplifier, but it can also be used as an oscillator. It is interesting to note that originally the local oscillator of FC radars was of this type. But most radars have shifted to the reflex klystron, which we will take up later.

A conventional electron gun produces a uniform density beam of electrons, all traveling at the same speed (fig. 9-9). The beam is the source of the tube's amplification power. The beam of electrons passes through a pair of closely spaced grids called buncher grids. Each grid is connected to one side of a tuned circuit. In this figure, lumped-constant components are shown. These components are equivalent to a resonant cavity at microwave frequencies. The

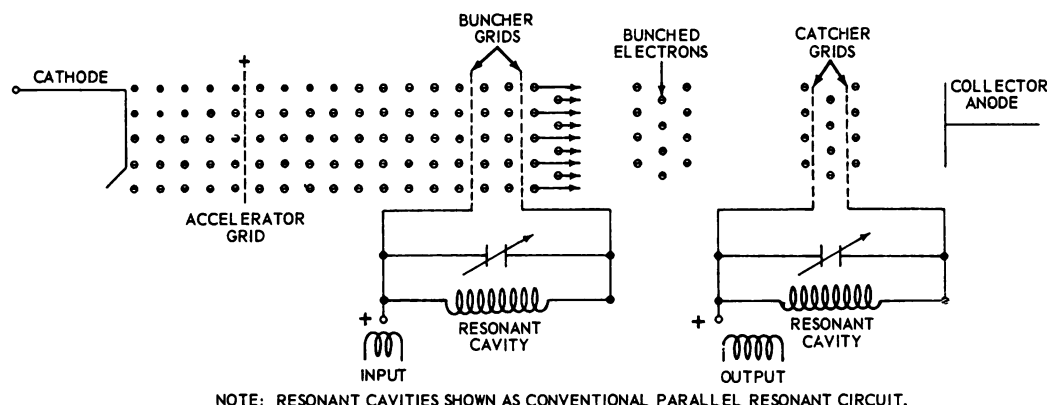


Figure 9-9.—Schematic diagram of a Klystron tube (2-cavity).

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tuned circuit and the grids are at the same d-c potential as the acceleration grid of the electron gun. Electron velocity, and the density of the beam approaching the grids, are uniform. The a-c potentials from the tuned circuit cause the velocity of electrons leaving the grids to differ. The tuned circuit produces the a-c potentials by the circulating current in its tank circuit. This circuit is initially excited by some irregularity such as transient noise voltages, random fields, or an initial unbalance when the circuit is energized. Hence the tuned circuit is oscillating at its natural resonant frequency. The a-c power in the tuned circuit is small since no signal has been introduced. But it is large enough to commence a small degree of electron bunching.

An oscillating electric field exists between the grids, due to their interelectrode capacitance. The strength of the field varies with the strength of the a-c potentials on the grids. The direction of the field varies at the frequency of the a-c oscillations. When this field aids the passage of electrons, they are accelerated; and when the field hinders the passage of electrons, they are retarded. In the area beyond the buncher grids, called the drift area, the accelerated electrons catch up to the retarded electrons, and bunches of electrons are formed. The frequency at which the bunches appear in the beam is proportional to the resonant frequency of the tuned circuit. As a consequence of velocity modulating of the electrons, the beam is now density modulated. Equal numbers of electrons

are accelerated and decelerated by the buncher grids. Thus the net transfer of energy between the beam and the tuned circuit is zero, if we disregard the small losses that occur in any circuit.

The bunched electrons pass through a second set of grids called the catcher grids. These grids are connected to a tuned circuit similar to that of the buncher grids. This tuned circuit establishes an electric field across the catcher grids. The transit time of the drift area is such that the electron bunches arrive at the grids when the field is in such a direction as to slow them down. As you know, when electrons are slowed down they give up energy to the force which slowed them. Hence, due to electron bunching, the a-c oscillations in the tuned circuit are reinforced by energy absorbed from the electron beam. After passing through the catcher grids, the electrons are absorbed by the collector.

At microwave frequencies the tube's tuned circuits are cavity resonators (fig. 9-10A). Energy is coupled into and out of the cavities by coupling loops or waveguide openings (windows). The signal input is coupled into the first cavity at its resonant frequency. The amplified output is taken from the second cavity. Amplification is possible because the electrons pass through the input grids in a continuous stream and through the output grids in definite bunches. If the output is fed back into the input cavity with the proper phase, the tube will operate as an oscillator.

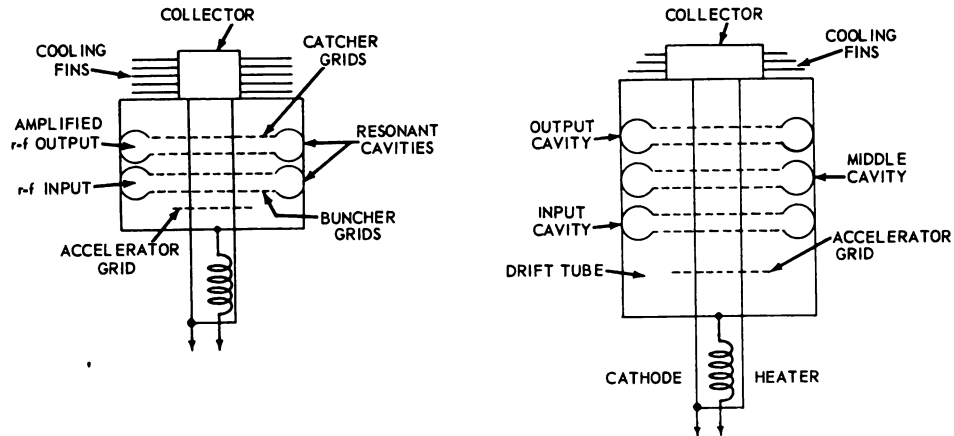


Figure 9-10.—Microwave Klystrons, multicavity.

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Three-Cavity Klystron

Amplification and efficiency are increased if we add a third cavity to the klystron (fig. 9-10B). The increase in gain of a three-cavity klystron is due to the increased number of times the electron beam is velocity-modulated. As in the TWT, the greater the modulation of the beam the more dense the electron bunches become and the greater the gain of the tube. But in klystrons this factor is more pronounced, due to the resonant circuits, the short distances in which the interaction between the signal and the beam takes place, and the relatively large a-c power necessary to provide sufficient bunching. In a two-cavity klystron, bunching takes place in a single stage. This is comparable to a stage of amplification in a conventional amplifier. Consequently, for a given output a relatively large input signal is required, since the tube's gain is low. In a three-cavity klystron the signal fed into the input/cavity produces a proportional voltage on the grids, which results in a certain degree of bunching. Although the density of the bunches may be low as they pass through the second or intermediate set of grids, they reinforce the power of the cavity oscillations. Since no power is extracted from the cavity, a large a-c voltage is present on the grids. This results in the electron bunches leaving the second set of grids to become more dense. This stage of the tube is comparable to the second stage of amplification in a conven-

tional amplifier, for the gain of the tube is determined by the degree of bunching in the beam entering the output grids. Obviously, the gain of a three-cavity klystron is larger than that of a two-cavity klystron. Klystrons are not limited to three cavities. The limit of gain, and hence of the number of cavities, is determined by the power available in the beam. The greater the power handling capability of a tube, the larger its physical size. In large power multicavity klystrons, magnetic fields are used to focus the electron beam. The focusing fields are generated by magnets or solenoids in an arrangement similar to that discussed under TWTs.

Multicavity klystrons are sometimes used as mixers, with one signal applied to the electron gun and the other to the first cavity. The signal to the electron gun is applied to the cathode or grid, to vary its bias. Hence the electron beam is intensity-modulated at the signal frequency. As an example, we will use 30 mc for this signal. The intensity of the beam leaving the gun is modulated at 30 mc. The second signal is an input to the first cavity, which oscillates at the signal frequency. Let's use the output of a radar's local oscillator, fLO, as the second signal. The input cavity grids velocity-modulate the electron beam which has been intensity-modulated by the first signal. The electron beam leaving the input cavity grids is in bunches representative of the beat frequencies of fLO, fLO+30mc, and fLO-30 mc. The

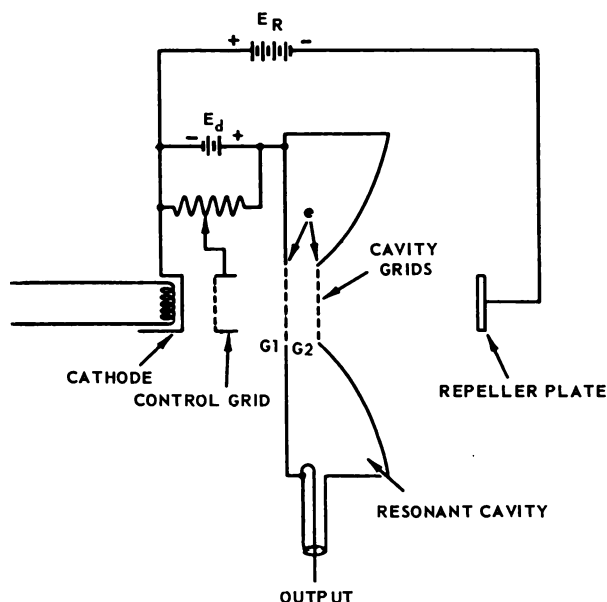
center and output cavities are tuned to one of these frequencies. Let's assume they are tuned to $f_{LO}-30$ mc; as a result, the lower difference frequency will be amplified, and extracted as the tube's output.

Reflex Klystron

A klystron used as a local oscillator in a radar receiver need not supply large amounts of power, but its output frequency must be stable and easily controlled. For example, in a radar whose r-f energy is at 9000 mc, a frequency shift of the local oscillator of 0.1 percent would result in a 9-mc shift of the intermediate frequency. This is greater than the bandwidth in most receivers, and would cause a considerable loss of amplification. A two-cavity klystron could be made to oscillate by positive feedback. But tuning a klystron tube, especially one using cavity resonators, is very difficult. You can realize this from the fact that frequency changes at a rate of approximately 200 megacycles per thousandth of an inch displacement of the grids. The reflex klystron is a simplified tube having only one resonant cavity and one set of grids. This type is used in most radars as the local oscillator.

Theory of Operation

In the circuit of the reflex klystron (fig. 9-11), note the arrangement of the electrodes and the voltages involved for operation. Electrons are emitted by an indirectly heated cathode. These electrons are attracted by the cavity grids (buncher grids) which are more positive than the cathode by the voltage E_a . The control grid is located between the cathode and the cavity grids and is for the purpose of controlling electron flow. It also has a positive potential which is usually about 200 or 300 volts. The electrons emitted from the cathode travel toward the cavity grids at velocity determined mainly by E_a . Most of the electrons pass through the control grid and the cavity grids, and continue on toward the repeller plate. After passing the cavity grids they approach a region where the electrical field opposes their motion, since the repeller plate is negative with respect to the cathode by the voltage E_r . This voltage is variable and equals about minus 100 volts. This, in turn, makes the voltage from repeller to cavity grids 300 or 400 volts. This slows down the electrons, causing them to come to a stop,



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Figure 9-11.—Circuit of a reflex Klystron oscillator.

after which they reverse direction and pass back through the grids.

Most of these returning electrons are collected by the cavity grid nearest the cathode, or by the accelerating grid or the shell. Those that are not collected continue on toward the cathode until they are reversed in direction by the accelerating field and sent back through the cavity a third time. These electrons that are not collected cause improper tube operation; this undesirable feature is partially overcome through tube design.

With the tank circuit oscillating, a high-frequency voltage, e , appears between the two cavity grids. This causes the electric field between these grids to reverse twice during each complete cycle of operation. In this condition, as the electrons approach these grids, the electron stream is uniform. The time that is required for the electrons to pass through the distance between the grids is small compared to the period of oscillations. Electrons which enter the space between the grids when e is zero will encounter no a-c electrical field and they will pass on through at the same velocity. The electrons which enter the space when e makes grid G_1 positive with respect to grid G_2 will encounter a field which tends to accelerate them. The amount of acceleration

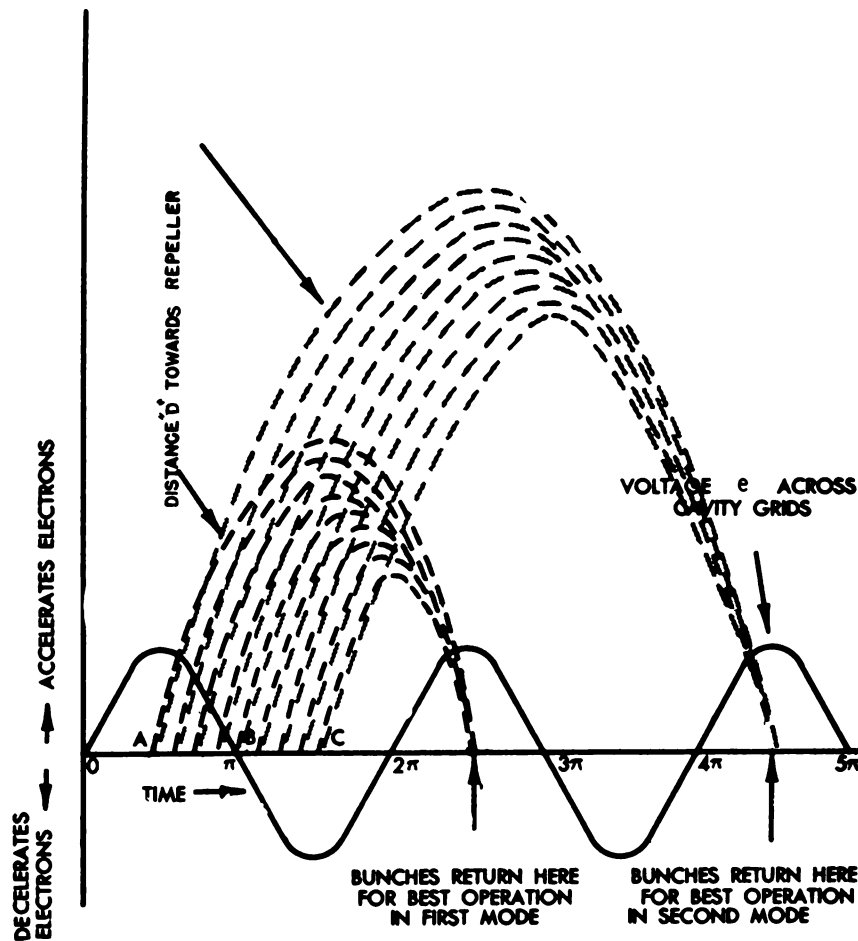


Figure 9-12. —Bunching action of a reflex Klystron.

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is a function of e . Electrons entering the space when e is reversed in polarity are decelerated. The change in velocity due to acceleration and deceleration is small in comparison with the original velocity. Those electrons which are accelerated most will travel farther toward the repeller plate before being turned back, while those that are decelerated most will be turned back sooner. Thus it is conceivable that with the proper magnitudes of e , E_a and E_r , electrons returning to the cavity grids will arrive in bunches.

Figure 9-12 shows the position of electrons in the tube at various times during their transit. The zero distance position, taken as the baseline in the graph, is midway between the cavity grids. Electron A, which arrives when G_2 is positive, is accelerated and travels farther before being turned back; electron B is unaffected;

electron C is decelerated and turns back after a shorter excursion. Hence, in the diagram these electrons and the ones passing through at intermediate times are shown as arriving back at the grids at the same instant of time. This is the ideal situation, but it is not difficult to see that electrons will return to these grids in a stream which varies in intensity at the frequency of the oscillations. Due to this fact this tube is called a REFLEX-VELOCITY-MODULATED tube because the electrons reverse direction and travel through the interelectrode space twice.

On the return trip the electric fields set up by the voltage e again act upon the electrons. Since they are now traveling in the opposite direction, they will be decelerated if they return when G_2 is positive and accelerated if they arrive when G_2 is negative. When an electron is

accelerated by an electric field, its kinetic energy increases; this additional energy is taken from the electric field. On the other hand, an electron which is decelerated gives up energy to the electric field. If the bunches of electrons can be made to arrive back when G_2 is positive, they will give up energy to the alternating field. For maximum transfer of energy the bunches must arrive when G_2 is maximum positive. The question arises as to where this energy originates. Remember that if the electron stream from the cathode is uniform, some electrons are accelerated and some are decelerated on the outbound trip by the electric field of e . On the average, as many electrons absorb energy from the field as give up energy to it. Hence, very little net energy is taken from the oscillating circuit during the bunching process. The average kinetic energy of the electron is that imparted to it by the d-c voltage E_a . Thus, some of the energy taken from the d-c electric field is transferred to the a-c field to sustain the oscillations. The power output is taken from the klystron with an inductance loop located inside the resonant cavity.

Klystron Thermal Tuning

The klystron local oscillator is normally tuned to operate at maximum output (klystron adjusted for maximum crystal current). The noise output of the local oscillator is at a minimum at this point. Maximum output is obtained when the klystron's cavity is resonant to the output frequency. A tuning mechanism is used to adjust the cavity dimensions of the klystron. In one type of tube the tuning mechanism is a part of the klystron. The upper section contains a triode (fig. 9-13). The length of the triode's plate changes with temperature variations. The temperature varies with plate current. An increase in plate current causes an increase in temperature, which makes the plate expand. The variations of the plate length are impressed through mechanical linkage on the cavity of the klystron. Thus, by controlling the grid voltage of the triode, and in turn its plate current and temperature, it is possible to vary the dimensions of the cavity in the klystron. The resonant frequency of the cavity varies with its dimensions. This method of tuning is known as THERMAL TUNING. In some klystrons a diode is used in place of the triode.

The diode's plate current is controlled by an external tube in series.

Tuning the klystron by varying the dimensions of the cavity is a mechanical adjustment. In thermal tuning the controls are in the klystron. In some radars the cavity dimensions are varied by external controls either manually or by a remotely controlled cavity tuning motor.

MAGNETRONS

In the FT2 course it was necessary to include the principles of operation of the magnetron in the discussion on radar. This was done so a clear picture of radar operation and testing techniques could be presented. Our purpose here is to place the magnetron in its proper group in the microwave tube field. These groups are determined by the tubes' operating principles. The tubes discussion so far in this chapter are in a group called the O-type.

The O-type tube is characterized by intensity, velocity, or density modulation of electron flow in the electric field axis (cathode to plate) of the tube. The modulation is a result of variations in the tube's electric field, or other electric fields such as those caused by a signal in the tube. The electrons flow in a relatively straight line. A cross-magnetic field may be used to focus the electrons into a sharp beam, but this magnetic field is not involved in the modulation.

In the M-type microwave tube, both an electric field and a cross-magnetic field are used to control the path of the electrons. The magnetron's operation puts it in this group. Since you are already familiar with the magnetron, we will use it to show the M-type characteristics. To do this we will use a brief summary of the magnetron's operation.

The magnetron is a special type of diode oscillator used to generate r-f energy. The magnetron extracts energy from an electric field and transfers this energy to an a-c field oscillating at a microwave frequency. A high-powered pulse applied between the plate and the cathode creates a strong electric field. Electrons leave the cathode and flow toward the plate as in a conventional tube. But the electrons encounter a cross-magnetic field which deflects them so as to alter their path. The electrons travel in a path which is determined by the balance of the two forces applied by the fields.

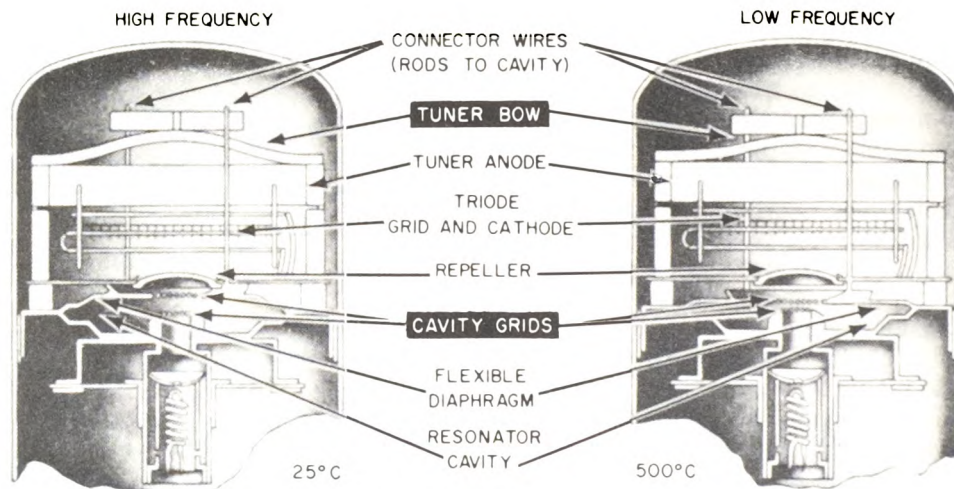


Figure 9-13.—Reflex Klystron.

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The plate contains cavity resonators which are initially excited by noise, and are oscillating at their resonant frequency. The tube is designed so that the r-f fields at the cavity gaps change in synchronism with electron motion. The fields' line of force may be considered as a traveling wave moving at synchronous velocity with the electrons. The traveling wave results in electron bunching. The bunches pass the gaps at the instant the fields cause maximum deceleration. Hence the electrons impart energy to the r-f fields. The magnetron output is coupled out from one of the cavities.

You can see that magnetron operation is similar to that of the TWT. If the magnetron were straight instead of round, we would have a conventional M-type TWT oscillator. The major difference between the O-type and the M-type tubes is the use of the magnetic field. In the M-type, the cross-magnetic field deflects the electron beam. Thus the electron beam can be brought closer to the interaction spaces, and the amount of interaction can be varied by the magnetic field's intensity. The M-type tube has a much higher efficiency than the O-type.

CRYSTALS

In a crystal, the atoms are arranged in a definite order, with uniform spacing. The study of crystal structure is beyond the scope of this course. An example, however, was covered in

your study of transistors. In one type of transistor, arsenic is added to a silicon crystal. The arsenic atoms occupy a definite position with relation to the silicon atoms. The properties of the crystal now include the characteristics of this relationship, and an N-type semiconductor is the result. This is but one example of a crystal manufactured to obtain desired properties. By varying the type of atoms and their proportions, many useful properties can be obtained.

Some of the characteristics of crystals, and samples of their application in fire control, are:

PIEZOELECTRIC EFFECT.—Crystals with this property will produce a voltage when under a mechanical stress, and vice versa. This type crystal is used in oscillator circuits.

FERROMAGNETISM.—Crystals with this property assume a spontaneous magnetic polarity when a field is applied. This type is used in microwave circuits (and is our next subject in the chapter), inductive coil cores, and memory devices.

LOW ELECTRICAL CONDUCTIVITY.—Crystals of this type have high resistivity to current flow. They are used as insulators and as dielectric material. Mica is an example of this type.

SEMICONDUCTIVITY.—This type crystal has conductivity greater than an insulator but lower than a conductor. This is the type of

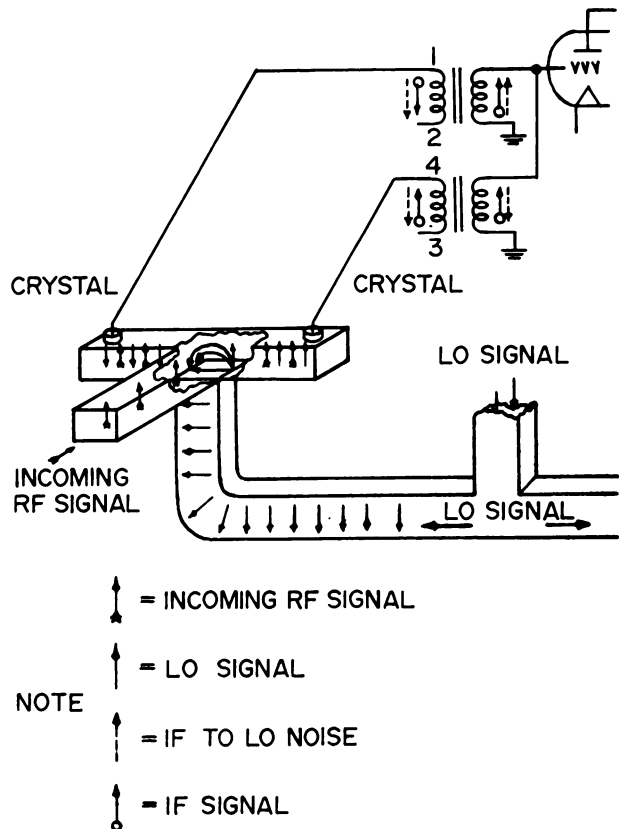
crystal used in transistors, rectifiers, detectors, and mixers. Hence this type is of prime importance to us. Transistors, rectifiers, and detectors are covered in Basic Electronics, NavPers 10087-A.

BALANCED MIXERS

Up until the last few years it has been impractical to amplify microwave signals. In the radar receiver the r-f signal is heterodyned with a signal from a local oscillator (LO) to produce an intermediate frequency. The LO signal differs from the r-f signal by the amount of the i-f signal. Normally, the desired i-f signal is 30 or 60 mc and the LO signal differs from the r-f signal by this amount. For example, if the r-f signal is 9000 mc, the LO signal may be 9060 mc, and the i-f signal is then 60 mc. Converting the modulation to a usable frequency is referred to as conversion, and is performed in the radar's mixer. Balanced mixers with silicon crystal diodes are used almost universally in fire control radars. A typical balanced mixer is shown in figure 9-14.

The operation of a crystal diode is explained in the basic electronics course. In a balanced mixer the crystal diode detects the intermediate frequency. Its effectiveness is usually expressed as the ratio of the reverse, or back, resistance to the forward resistance. A perfect detector would have an infinite back resistance and a zero forward resistance. Thus the detector acts as a rectifier, and has the nonlinear property of a rectifier in that it will pass current only in the forward direction. In this direction the crystal operates as a linear detector and the output is linearly dependent on the amplitude and frequency of the inputs. Transit-time effects are minimized by the small physical size of the point contact in the crystal.

In figure 9-14 the LO signal is introduced into the mixer assembly by an H-type junction. Hence the LO signal arrives at the crystals in phase and equal in amplitude. The r-f signal is introduced by an E-type junction and arrives at the crystals 180° out of phase and equal in amplitude. Thus at one crystal the LO and r-f signals are in phase while at the other crystal the two inputs are 180° out of phase. As a result, the i-f outputs of the crystals are 180° out of phase and equal in amplitude. The outputs of the crystals are applied to the primary windings of the transformer. The two secondary windings



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Figure 9-14.—Schematic diagram of a balanced converter.

of the transformer are wound in reverse directions and are connected in parallel. Therefore the two signals will add in the secondary and the i-f power output will be the sum of the inputs to the crystals. This arrangement will cancel noise generated in the LO. Since the LO signal, and hence the noise, arrives at the crystals in phase, the crystal output due to this noise is in phase. In the secondary of the transformer the two noise voltages which are now 180° out of phase will cancel.

Fire control radars normally have two balanced mixers. In one of these mixers a sample of the transmitted r-f energy is mixed with the LO signal to obtain an i-f voltage. This voltage is used in the automatic frequency control (AFC), circuits in the radar. The i-f voltage is the input to a discriminator which electronically senses any frequency shift from resonance. The discriminator's output furnishes a signal to the thermal tuning circuit of the LO (reflex klystron). This results in a change in the LO

frequency and a return to the correct intermediate frequency. In the other balanced mixer the LO signal is mixed with returned echo signals. The r-f echo signal is applied to the crystals 180° out of phase, and the resulting i-f voltage is the sum of the outputs of the crystals. Thus any modulation of the transmitted energy present in the echo signal is also present in the i-f signal. This i-f signal is amplified and modified to furnish video display, target position measurements, and radar control signals.

Figure 9-15 shows a microwave crystal. The cat whisker, a fine wire, makes contact with the crystal of pure silicon. This contact establishes the characteristics of the crystal, and is carefully adjusted at the factory. A filler material is used to give the wire rigidity. Despite this type of construction the crystal is shock-sensitive and must be handled carefully. A slight jar may change the nature of the contact and result in a change in the crystal's characteristics. Crystals can be easily damaged by r-f fields, static discharges, and excessive current. The sensitivity of crystals may change over a period of time. In a balanced

mixer the crystals must have as nearly identical characteristics as possible. Hence, when crystals are replaced, a matching pair should be selected. A figure which is representative of the crystal's characteristics is obtained by measuring the d-c crystal current. This is normally monitored by an installed meter. The d-c crystal current is a result of the nonlinear characteristics of crystals used as detectors.

FERRITES

Before the use of ferrites became possible at microwave frequencies, the r-f energy in a radar was manipulated by varying the characteristics and dimensions of the r-f system. The important point is that the system was made to conform to the microwave frequency, and not the microwave to the system. The r-f system was tuned to a given frequency by adjustments whose values were determined by that frequency. But the frequency stability of a microwave r-f generator, a magnetron for example, is dependent upon the impedance into which it works. In a typical radar, a relatively large and time-varying mismatch (as in the case of a scanning

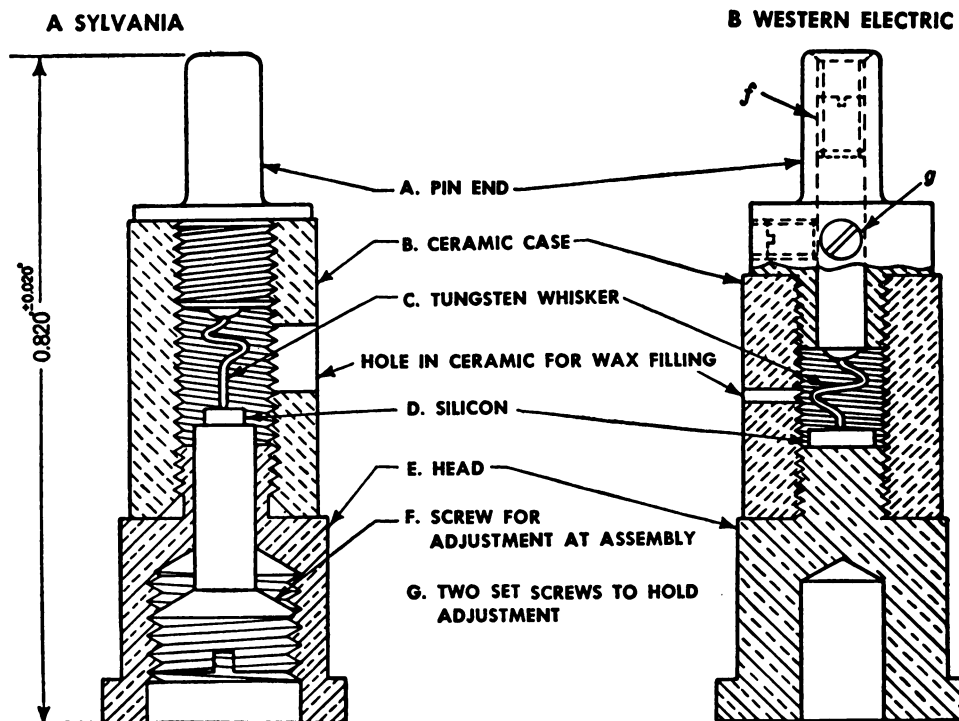


Figure 9-15. —Crystal cartridges.

antenna fed by flexible joints), may be connected to the magnetron. A mismatch often causes excessive frequency pull on the magnetron, throwing the transmitter out of tune. Ferrites have unique magnetic properties that provide a variable reactance, which makes it possible to adjust or manipulate the microwave energy to conform to the transmission system, and to electrically vary the characteristic impedance of the radar's r-f system. Ferrites are a recent development with expanding applications in radars. At present they are used as load isolators, phase shifters, variable attenuators, modulators, and switches. Since ferrites are new, a brief and general description of the fundamental theory of ferromagnetism should be helpful.

FUNDAMENTALS OF FERROMAGNETISM

The theory of ferromagnetism is a continuation of the conventional theory of magnetism. In Basic Electricity, NavPers 10086-A, the magnetic domain theory is introduced without suggesting the nature of the domain. This coverage is sufficient for conventional magnetism. To understand ferrites, however, the nature of the domain must be known. An individual domain obtains its overall magnetic properties from the perpetually moving electrons within its atomic structure.

An electron has two angular motions within its atom. The orbital motion of the electron about the nucleus is well known. A less familiar motion is the electron's spin about its own axis. The electron's motions are comparable to the earth's orbital motion about the sun and its axial rotation.

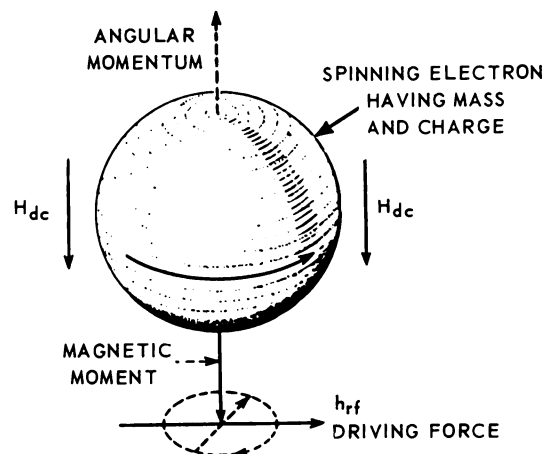
The electron is a negatively charged particle of matter. Since the electron has an electrical charge, its motion is a current flow within the atom. Due to this current flow, magnetic fields exist perpendicular to the electron's motions. The electron's orbital magnetic fields contribute little to the magnetic properties of the domain. It is the magnetic fields created by the spin motion of the electrons that combine to make up magnetic domains. Atoms of most elements have as many electrons spinning in one direction as the other, so that the magnetic fields of the electrons cancel out. These elements do not have any noticeable magnetic effects. The iron atom, however, has four more electrons spinning in one direction than in the other. The uncanceled magnetic fields of these electrons

make the iron atom a permanent magnet. Incidentally the prefix "ferro" in ferromagnetism means iron. When the uncompensated magnetic fields in adjacent atoms become mutually aligned, the fields add and a magnetic domain is established. The magnetic domain, also called an elementary magnetic dipole, exhibits appreciable amounts of magnetic force. The individual domains are normally arranged in a random manner within the material, and their magnetic properties cancel. When an external d-c field is applied, the spin axes of the electrons in the domains align with the field (fig. 9-16). This is due to the interaction between the electrons' magnetic fields and the external field. As a result the domains become mutually aligned and their magnetic fields add.

If the external field is removed, the magnetic domains tend to remain in mutual alignment.

As a consequence of their spinning motion, electrons behave like small gyroscopes. You know that gyros have the properties of rigidity and precession. Since gravity has little effect on the electron due to its small mass, a steady d-c magnetic field can line up the axes of the spinning electrons. The electrons, possessing rigidity of plane of rotation, tend to remain aligned with a point in space which coincides with the applied field's axis.

The theory that an electron has the properties of a gyro is used to explain the behavior of a ferrite. Electron precession in a ferrite is



92.78

Figure 9-16.—An electron aligned with a d-c magnetic field.

caused by the electron's orbital motion about the nucleus, and the force within the material which holds it together. When a static magnetic field is applied, the electrons tend to align their spin axes with the newly applied force. The electron wobbles on its spin axis to establish a state of equilibrium between the internal binding force and the field force. As a result of the two forces the electron wobbles on its spin axis at a natural precessional frequency. This frequency varies with the strength of the applied field. The net direction of the spin axis of the electron remains aligned with the field's axis.

Ferrite Materials

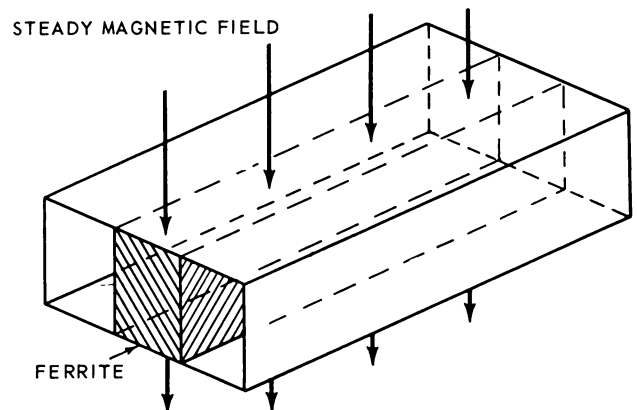
Ferrites are unique in that they have useful magnetic properties and at the same time high resistivity to current flow. This combination is not found in conventional ferromagnetic materials. Iron, for example, has good magnetic properties but a relatively low resistance to current flow. The low resistance enhances current flow in iron which causes significant eddy currents and their associated power loss at high frequencies. On the other hand, ferrites' resistance is high enough for them to be classed as semiconductors. Ferrites to be used at high frequencies are made of high-dielectric materials which are transparent to microwave energy. Thus r-f energy can pass through ferrites.

Since you will never be called upon to manufacture a ferrite, a brief discussion to explain their seemingly contradictory properties will be sufficient. To achieve the desired characteristic, ferrites are made of compounds. The primary compound is normally iron oxide. Added to this are various impurities, mainly consisting of oxides of other elements, to obtain the exact characteristics needed for a particular application. The compounds retain the magnetic properties of the ferromagnetic atom (such as iron, nickel, zinc, and magnesium), but the electrical conductivity of the compound is reduced by the addition of the impurities. This is a statement of fact, the proof of which is beyond the scope of this course. The composition of ferrites, however, is comparable with compounds used in transistors which are semiconductors familiar to you. By the proper choice of the proportions and the types of atoms, ferrites with a wide range of magnetic and electrical properties can be produced. Although it is not pertinent in this discussion it

is interesting to note that ferrites are widely used in computers, television, and magnetic recording tapes, as well as in many other fields.

FERRITE ATTENUATOR

To attenuate a particular radio frequency and to allow other frequencies to pass with little attenuation, a ferrite is placed in the center of a waveguide. The ferrite is positioned so that the electron's magnetic field is perpendicular to the r-f energy in the guide, (fig. 9-17). Thus the r-f energy will be applied in the torque axes of the spinning electrons. The electrons are precessing at a resonant frequency before the r-f energy is felt. If the r-f energy has the same frequency as the resonant precessional frequency of the electron, the precession will grow greater due to the r-f force. This is because the phase of the r-f energy will always be adding to the precession of the electron. Since the electron's spin axis is moved during precession, energy is used. This energy must come from the force causing the increase in precession, which is the r-f wave. Hence the r-f energy is attenuated by the ferrite and is given off as heat. If the wave is not at the electron's resonant frequency, energy is still absorbed from the wave when it increases precession. But the wave and the electron's precession have different frequencies; consequently the wave will also act to reduce the electron's precession. This is determined by the phase relationship between the fields of the two frequencies. When the



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Figure 9-17.—Ferrite attenuator.

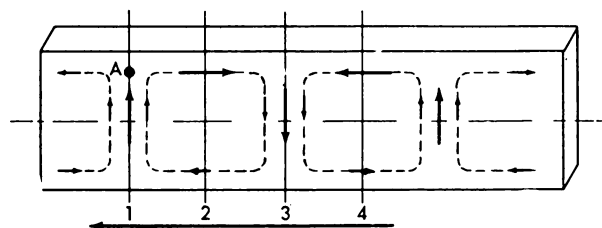
electron precession is reduced, the wave extracts energy from the electron's magnetic field. Thus there is only a slight attenuation of the r-f energy. The resonant frequency of electron precession may be varied over a limited range by changing the strength of the applied d-c field.

ONE-WAY ISOLATOR

An electromagnetic wave traveling down a waveguide will produce, at a point off the centerline of the guide, a rotating magnetic field. This is illustrated in figure 9-18. When the wave is moving from right to left, the magnetic field at a stationary location, A, will be pointing up, as shown. As the wave pattern moves along so that point 2 is at A, the magnetic field is directed right. Similarly, as points 3 and 4 on the wave arrive at A, the field direction will appear to rotate clockwise. Thus, any point off the center of the waveguide will see a rotating magnetic field as the electromagnetic wave goes by.

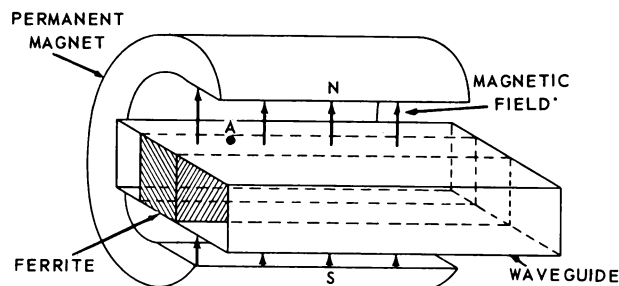
By applying the same analysis as is illustrated in figure 9-18 to a wave traveling from left to right, we can demonstrate that the magnetic field at A will now rotate counterclockwise.

A piece of ferrite can be placed in the waveguide at A, as shown in figure 9-19. The d-c magnetic field is applied, and either the magnetic field strength or the microwave frequency is adjusted to make the ferrite's electron resonant frequency equal to the microwave frequency. Now, if a wave travels down the guide from left to right, it will act as a rotating force on the electrons in the iron atoms in the direction of natural precession. The precession will build up to a very high amplitude and cause the power absorbed from the electromag-



92.80

Figure 9-18.—Rotating magnetic field at point A.



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Figure 9-19.—One-way isolator.

netic wave to be dissipated in the ferrite as heat.

A wave traveling from right to left will not suffer much attenuation. Its rotating magnetic field will attempt to push the electrons around in the opposite direction to their natural precession and no large movements will occur. Thus a wave traveling from left to right will suffer as much as a 10-decibel attenuation, but one traveling from right to left will lose only about 0.4 decibel.

FARADAY ROTATION

When microwaves are passed through a piece of ferrite in a magnetic field, another effect occurs. If the frequency of the microwaves is well above the electron resonant frequency, the plane of polarization of the wave will be rotated. This is known as the Faraday rotation effect, and is illustrated in figure 9-20. A rod of ferrite is placed along the axis of the waveguide, and a d-c magnetic field is set up along the axis by a coil. Suppose a wave entering at the left end is vertically polarized. As it enters the section containing the ferrite, it will set up limited precession motion of the electrons. The magnetic fields of the wave and the precessing electrons interact, and the polarization of the wave is rotated. Upon leaving the ferrite, the wave is polarized at a 45-degree angle if we have chosen the correct length of ferrite.

A more accurate explanation of the Faraday rotation may be made by considering the linearly polarized wave as the sum of two circularly polarized waves rotating in opposite directions. The component wave that is rotating in the same direction as the natural precession motion of the ferrite electrons will have some of its energy absorbed, while the counter rotating component will not lose energy. This causes the velocity of

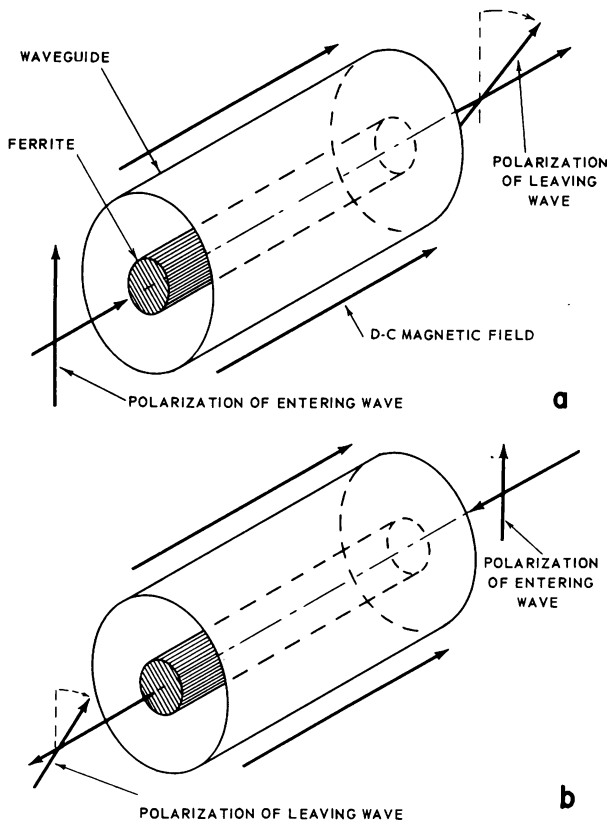


Figure 9-20.—Faraday rotation.

propagation for the former component to be somewhat less than for the latter, and the plane of polarization is rotated in the direction of the faster moving wave. For any type of ferrite, the angle of rotation is proportional to ferrite length and the strength of the d-c magnetic field; it does not depend on frequency.

The most important effect of the Faraday rotation is that the direction of rotation depends only on the electron spin in the ferrite, so that a wave going past the ferrite rod in figure 9-20 will always be twisted as shown, regardless of which direction it is traveling. The direction of rotation may be changed by reversing the d-c magnetic field in the ferrite.

FERRITE ISOLATOR

A practical device utilizing the Faraday rotation is shown schematically in figure 9-21. A plane-polarized wave comes down the guide and goes through a rectangular-to-round waveguide transition. As the wave passes the ferrite,

its plane of polarization is rotated 45 degrees clockwise, and enters the rectangular output waveguide, as shown in figure 9-21A. However, if a wave comes down the guide in the reverse direction, it will also be rotated 45 degrees clockwise, as shown in figure 9-21B, and will be at 90 degrees to the plane of the rectangular output waveguide. The waveguide cannot accept this cross polarized wave, and the energy will be reflected. Properly oriented vane type absorbers will absorb this energy without affecting waves traveling in the forward direction.

In isolators designed to handle high power, the reflected wave—after its polarization is rotated—can be coupled out to a separate power absorbing load. An isolator of this type is shown in figure 9-22.

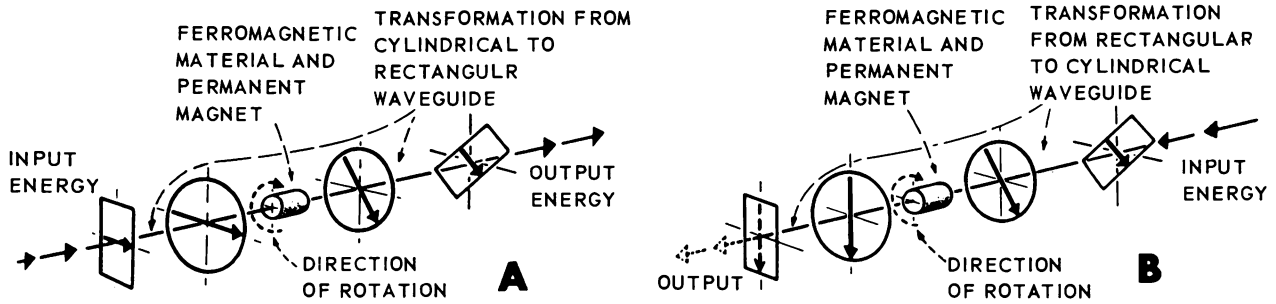
Isolators of the Faraday rotation type are capable of handling more power than the ferromagnetic resonance type, since the reflected energy does not have to be dissipated in the ferrite. Some modern isolators of the Faraday rotation type can provide 30-decibel attenuation in the reverse direction for only 0.1 decibel forward loss. The most important use of one-way isolators is to keep reflected energy (standing waves), from the microwave generator. This isolator acts as a switch and is often referred to as a ferrite switch.

This type of one-way isolator can normally be installed in the radar's plumbing system as a unit. The d-c magnetic field is established along the ferrite's axis by a permanent magnet. The input and output waveguide flanges of the unit have a 22.5° twist.

VARIABLE ATTENUATOR

A variable ferrite isolator uses an electromagnet around the guide as shown in figure 9-23. A wave, entering the left side, comes in polarized with its E lines horizontal as shown. If there is no coil current, it will pass the ferrite with no rotation, and suffer 3-decibel attenuation in entering the rectangular output guide that is mounted at a 45° angle. If current flows through the magnetizing coil in one direction, the ferrite will twist the wave polarization 45° to the left and it will enter the output guide with almost no loss. Coil current in the opposite direction will twist the wave polarization to the right and the wave cannot enter the output guide. The wave is reflected and absorbed by the cross polarization vane attenuator. This permits the attenuation of a wave to be varied from 0.1 to 30 decibels merely by changing coil current.

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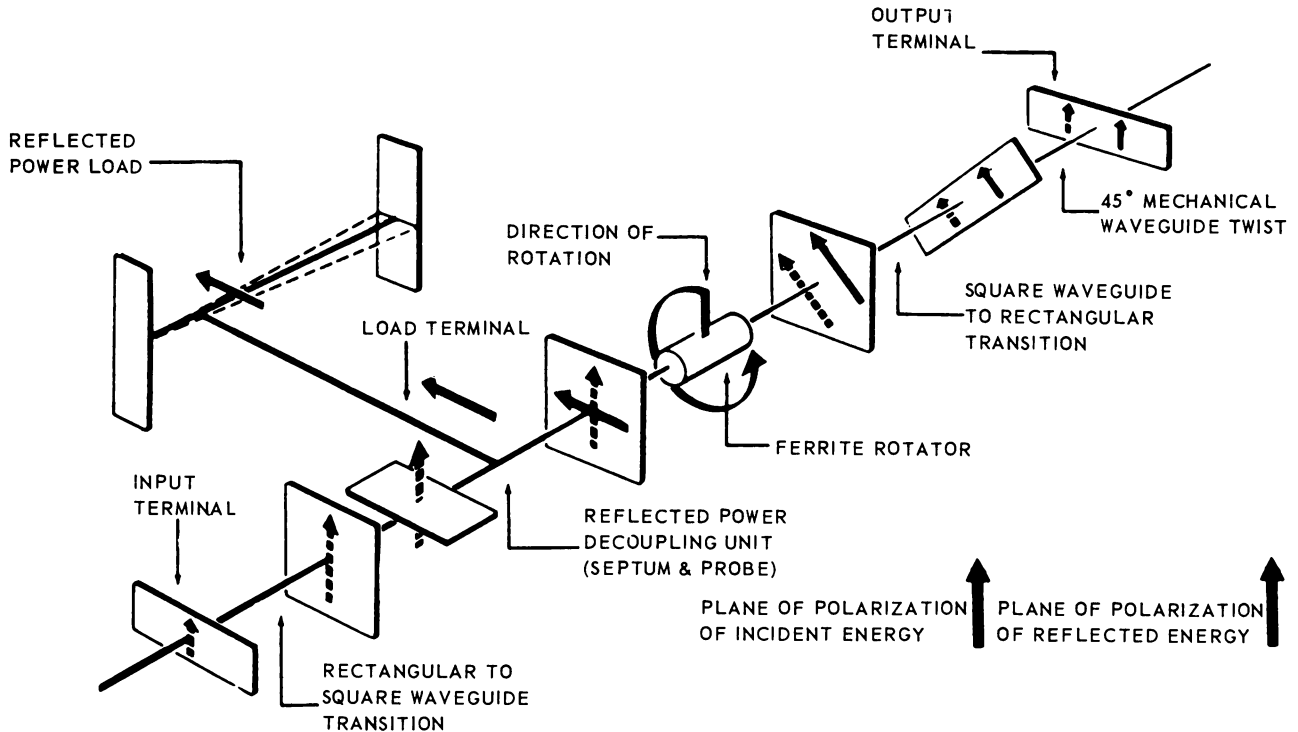


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Figure 9-21.—Ferrite isolator: A. Wave traveling in the forward direction; B. Wave traveling in the reversed direction.

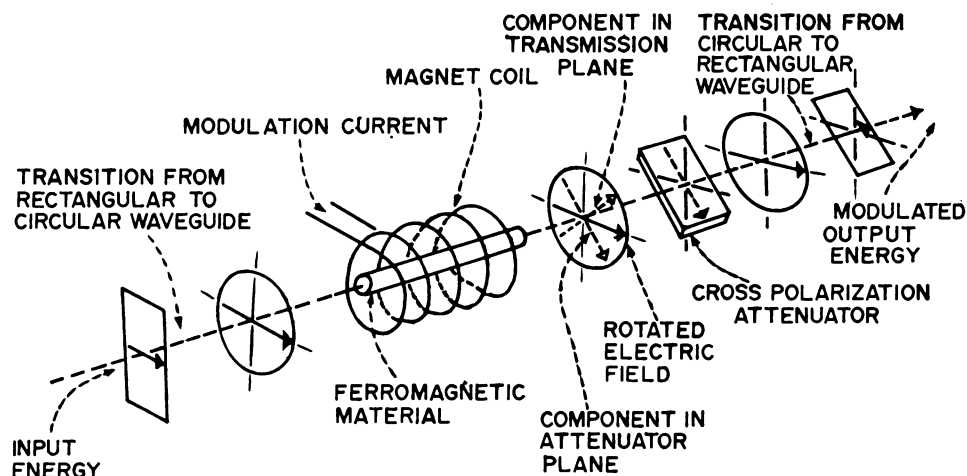
This device can be used to produce an amplitude modulated microwave output merely by feeding the magnetizing coil with the output of an audio amplifier. It permits a constant frequency and amplitude wave to be amplitude modulated with no attendant frequency modulation.

Another important application is in the receiver section of a radar set. A variable attenuator can be placed just before the receiver detector crystals. When the transmitter pulse is about to be generated, a step current can be applied to the variable attenuator to cause maximum attenuation. This will protect the crystals



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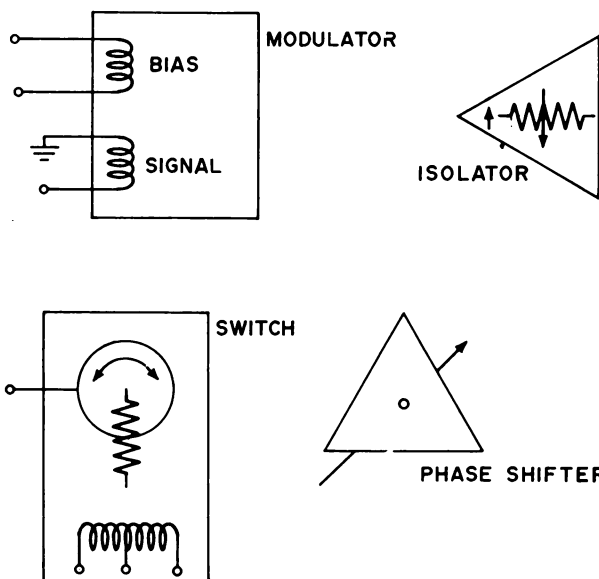
Figure 9-22.—Ferrite isolator with separate, reflected-power-absorbing load.



92.85

Figure 9-23. —Ferrite isolator with variable attenuation.

before the transmitter pulse hits them. After the pulse, the attenuation can be reduced slowly, protecting the crystals from strong reflections from nearby objects and providing automatic gain control as the range increases. This type of attenuator cannot, of course, protect the crystals from the "main bang" that may enter the antenna from another nearby radar set. Figure 9-24 is an illustration of schematic symbols for ferrite devices found in the equipment OPs.



92.86

Figure 9-24. —Schematic symbols for Ferrite devices.

CHAPTER 10

RADAR ANTENNAS

INTRODUCTION

Antennas are devices used to radiate electromagnetic energy into space, and to receive electromagnetic energy from space. The characteristics of transmitting and receiving antennas are similar, so that a good transmitting antenna is also a good receiving antenna. A single antenna performs both functions in a radar set.

This chapter deals exclusively with antennas used in fire control radars. These radars operate in the S, C, and X bands, which are in the microwave range. A list of the frequency bands, their designators, and wavelengths is contained in an appendix of this text. The basic principles of operation for antennas in the microwave range are the same as those used at lower frequencies. These principles are covered in Basic Electronics, NavPers 10087-A. We recommend that you review this material in the basic text.

Radar is used in various ways in the solution of the fire control problem. For one thing, it establishes the tracking line. To do this, fire control radars must have high directivity. Directivity refers to the sharpness or narrowness of the radiation pattern. Antenna characteristics are a major factor in determining the radiation pattern.

TYPES OF FIRE CONTROL ANTENNAS

It is probable that you are familiar with some fire control antennas. A brief description of the various types found in the fleet is included in this course for completeness. We cannot include the actual dimensions of radiated patterns, because that is classified information. The figures are given in the radar OPs. But we can cover the underlying reasons for the different patterns as determined by antenna configuration. Before

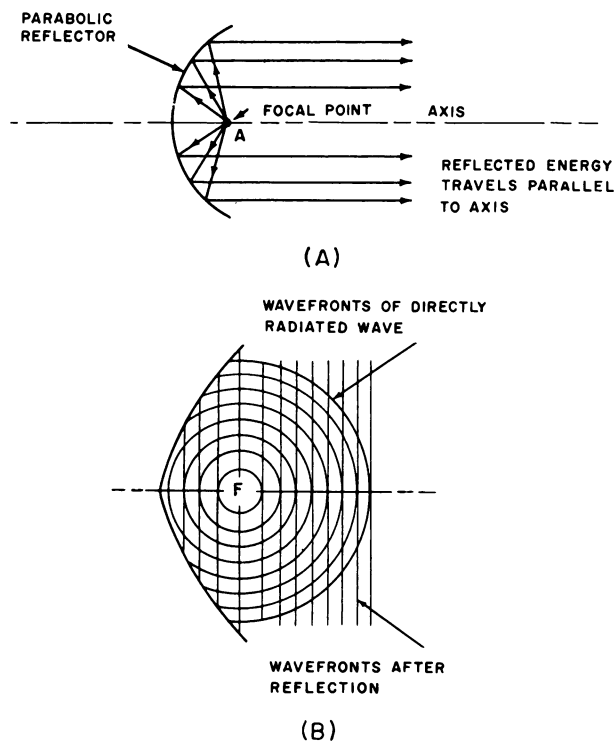
proceeding, we should reaffirm the fact that radar energy has a wavelength in the microwave range, and has properties similar to those of light waves. For example, r-f energy can be reflected and refracted.

PARABOLIC REFLECTORS

The parabolic reflector is one directional device used at microwave frequencies. If a point source is placed at the focal point, A, in figure 10-1A, the reflector concentrates the radiation from the source into a beam, much as a searchlight reflector concentrates a light beam. The parabola converts the spherical waves, as radiated by the point source, into plane waves (fig. 10-1B).

One form of parabolic reflector is the paraboloid of revolution, or rotational parabola. This is the surface generated by the revolution of a parabola about its axis; it somewhat resembles an eggshell cut in half at right angles to the long axis. Figure 10-2 shows a cross-section view of a rotational parabola, which is excited by a feed horn located at the focal point inside the parabola. The feed horn radiates the r-f energy back toward the paraboloid through two apertures, (fig. 10-3). By this means, direct radiation is eliminated; the beam is made sharper, and power is saved. Without this type of feed, some of the radiated field would leave the radiator directly. Since it would not be reflected, it would not become a part of the main beam and thus could serve no useful purpose. Another method of accomplishing the same result is through the use of a parasitic array to direct the radiated field back to the reflector.

The radiation pattern of a rotational parabola contains a major lobe, which is directed along the axis of revolution, and several minor lobes, as shown in figure 10-4. Very narrow beams are possible with this type of reflector.

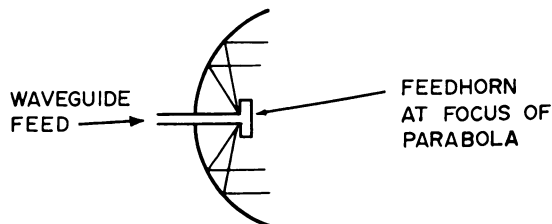


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Figure 10-1.—Parabolic reflector.

Truncated Paraboloid

The truncated paraboloid (fig. 10-5) is a section of a full paraboloid. The upper and lower portions of the paraboloid, represented by dashed lines in the illustration, are not used. For the horizontally mounted truncated parabolic reflector (for example, the Mk 13 surface radar's antenna shown in figure 10-6), the width of the horizontal plane beam is essentially the same as it would be without the truncation. Thus, the radiated pattern of the Mk 13 radar is narrow in the horizontal plane. The antenna assembly is rocked in this plane to obtain a sinusoidal



13.45

Figure 10-2.—Cross-section of paraboloid.



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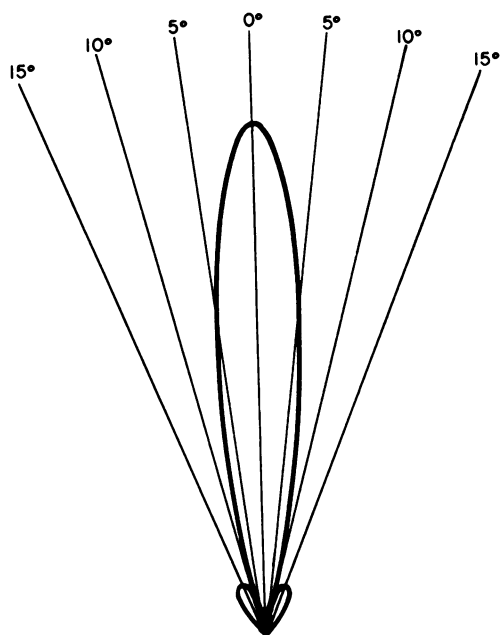
Figure 10-3.—Dual aperture rear feed horn (Culter).

scan. Accurate bearing information is obtained by this type scan and antenna configuration.

It is practical to construct the reflecting dish in the form of a grate or mesh, rather than a solid surface. You have undoubtedly seen grated reflector dishes. Note this feature in the Mk 13 radar illustration. The electromagnetic properties of a grated reflector are similar to those of a solid reflector. The grated dish will reflect satisfactorily if the material in the grating lies in the plane of the radiated waves. This plane is determined by the polarization of the antenna feed system. As stated in the basic text, the plane which contains the electric lines of force determines the polarization of the wave.

Parabolic Twist Reflector

The parabolic twist reflector antenna is also referred to as a Cassegrainian antenna. In the antenna, the energy is initially radiated from a



1.257

Figure 10-4.—Pattern of rotational parabola.

point source—in our example a feed horn—and is polarized so that the E lines are in a definite plane. Assume the waves are horizontally polarized and the grating strips of the reflector in figure 10-7 are aligned parallel in the vertical plane. This surface would be transparent to the wave and the energy would pass through the dish and not be reflected.

If the grating strips in the reflector dish were rotated so that they were in the same plane as the wave, the grate would reflect the wave. The reflected wave is reversed in phase 180 degrees. Although there is a phase reversal, the polarization of the wave does not change. Each point on the reflector can be regarded as a point source of energy. By controlling the contours of the dish the reflected rays can be made convergent, divergent, or parallel.

Now let's see what would happen if the grating strips were rotated so as to make a 45° angle with the wave's plane. The E fields of the incident energy are resolved into two components, one parallel and one perpendicular to the grating (fig. 10-8). The perpendicular component will pass into the dielectric material while the parallel component is reflected by the grating. A metal plate located one-quarter wavelength behind the grating reflects the component which penetrated the dielectric material. This arrangement is such that this component of the

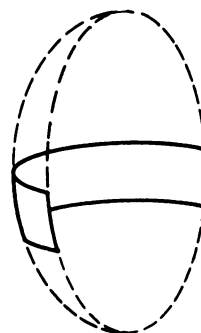
wave has the same phase when leaving the dielectric as it had when entering. The component of the wave reflected by the grating is changed 180 degrees in phase. Due to the antenna arrangement the reflected waves are 90° out of phase with each other. Therefore when the reflected waves recombine, the resulting polarization (vertical) is perpendicular to the incident polarization (horizontal).

From the preceding explanation we know that a grated reflecting surface can be made so that it will transmit a wave with one type polarization and reflect a wave with a different polarization. In a Cassegrainian antenna, a reflector dish with grating strips horizontally mounted is placed in front of a parabolic twist reflector, (fig. 10-9). The forward reflector is transparent to vertically polarized waves and will reflect horizontally polarized waves. The r-f source is horizontally polarized and its waves are reflected by the forward reflector. The reflected waves strike the twist reflector and are rotated to the vertical plane. The waves can now pass through the forward reflector.

LENS ANTENNA

At microwave frequencies, the conversion of spherically radiated energy into a wave consisting of mutually perpendicular E and H lines (plane wave) in a given direction can be accomplished by using a point radiating source in conjunction with a collimating lens. The point source, which is the open end of a waveguide, can be regarded as a gun which shoots the r-f energy toward the lens. The antenna thus formed is referred to as a "lens antenna."

The lens (fig. 10-10) consists of several parallel concave metallic strips which are



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Figure 10-5.—Truncated paraboloid.

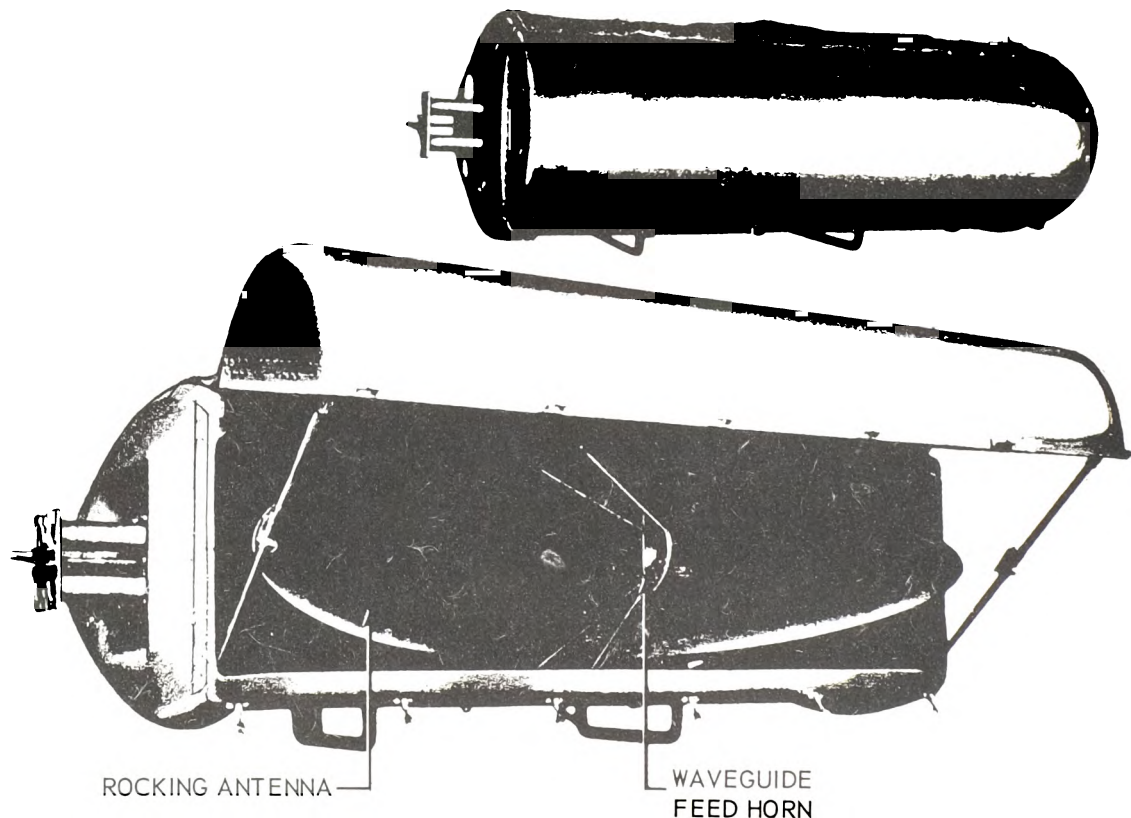


Figure 10-6. —Antenna assembly Mk 13 radar.

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placed parallel to the electric (E) field of the radiated energy fed to the lens. For the incident wave, these strips act as waveguides in parallel. The strips are placed slightly more than a half wavelength apart.

The radiated energy consists of an infinite number of radial sections or rays. Each of the radial sections contains mutually perpendicular E and H lines, both of which are perpendicular to the direction of travel. Because each of the radial sections travels in a different direction, the point source in itself has poor directivity. The purpose of the lens is to convert the input spherical r-f segment (which consists of all of the radial sections) into parallel or collimated lines in a given direction at the exit side of the lens. The focusing characteristic of the lens is accomplished through the refracting qualities of the metallic strips.

To understand the collimating effect of the lens, it is necessary to consider the fact that the phase velocity of the electromagnetic energy propagation through metals is greater than

through air. Because of the concave construction of the lens, wavefronts arriving near the

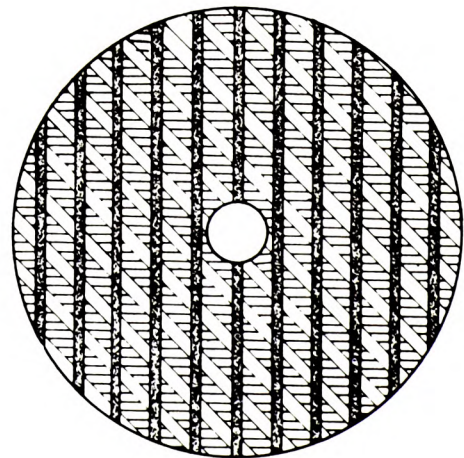
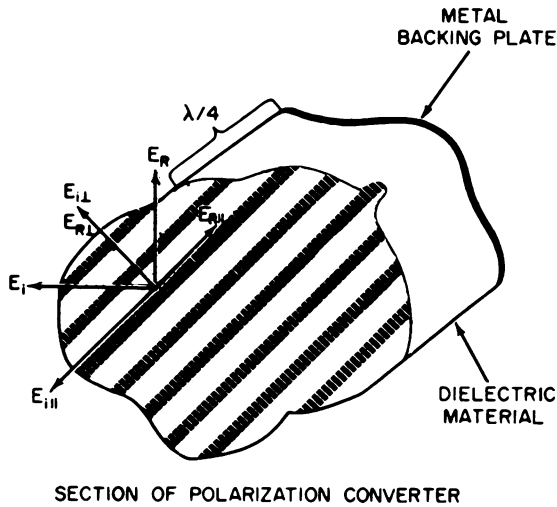


Figure 10-7. —Reflector with grating strips in the vertical plane.

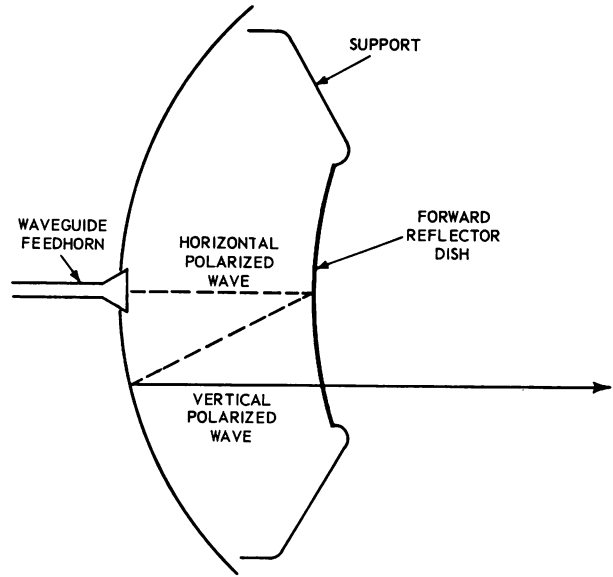
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- E_i = E FIELD OF INCIDENT ENERGY
 E_{iH} = COMPONENT OF E_i PARALLEL TO THE GRATING
 E_{iL} = COMPONENT OF E_i PERPENDICULAR TO GRATING
 E_r = E FIELD OF ENERGY REFLECTED FROM POLARIZATION CONVERTER
 E_{rH} = COMPONENT OF E_r PARALLEL TO GRATING
 E_{rL} = COMPONENT OF E_r PERPENDICULAR TO GRATING

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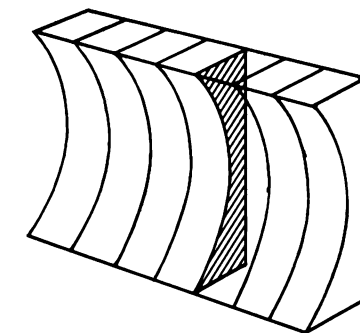
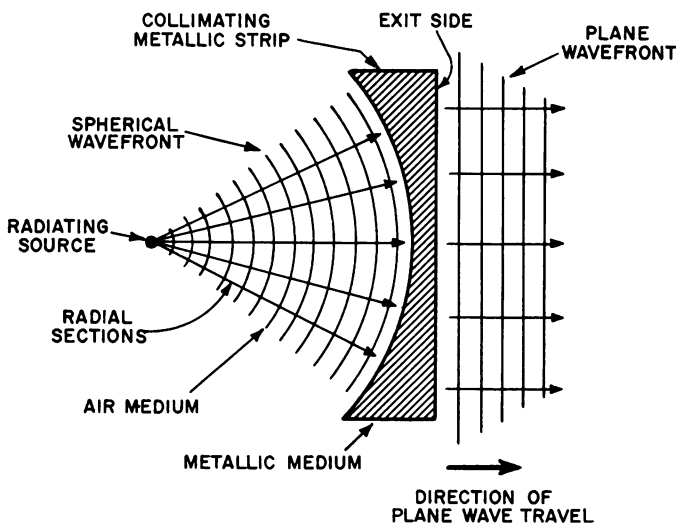
Figure 10-8.—Vector representation of Polarization conversion.



92.91

Figure 10-9.—Parabolic Twist Antenna (Cassegrainian).

ends of the lens are accelerated more than those arriving near the middle. Therefore, the portions of the spherical wavefront near the ends of the lens travel farther than those at the center in the same amount of time. Thus, the wavefront emerging from the exit side of the lens appears as a plane wave, now consisting of an infinite number of parallel sections with both the E field and H field components mutually perpendicular to the direction of travel.



THREE DIMENSIONAL VIEW OF PARALLEL-PLATE LENS

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Figure 10-10.—Lens Antenna.

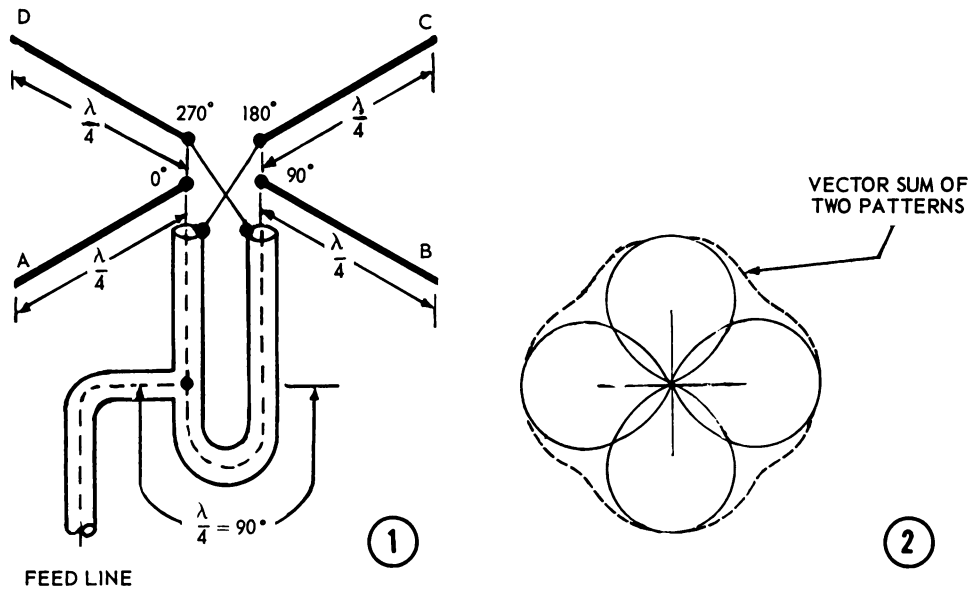


Figure 10-11. —Turnstile Antenna.

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TURNSTILE ANTENNA

Turnstile antennas are used in radar receivers in some missiles and in the alignment of missile fire control radars. The turnstile antenna is composed of two dipoles mounted perpendicular to each other with their axes intersecting at the center, (fig. 10-11). The antenna and its receiving lines are connected in such a way as to give a 90° phase shift between adjacent receiving elements. The strength of a signal received perpendicular to a plane containing two of the elements is equal to the field intercepted by those elements alone. The signal strength received at any other angle is equal to the vector sum of the signals inducted in all the elements. The vector sum of the signals from the elements at any angle is nearly equal to the signal strength when received broadside to a dipole. Thus by measuring and comparing the signal strength received in the dipoles, the relationship between the transmitting radar's beam axis and the axes of the dipoles can be established. In this manner we can determine the power received by the antenna in each quadrant and establish the location of the beam axis. If the transmitted beam is nutated, no amplitude modulation should appear in the turnstile antenna receiver's video when the beam axis is aligned with the antenna axis.

ANTENNA CHARACTERISTICS

The electrical characteristics of low frequency antennas are covered in the basic electronic text. As previously mentioned the principles, hence the characteristics, are similar. Furthermore, normal shipboard maintenance of radar sets requires only a fundamental knowledge of antenna theory. Antenna theory is primarily a design and installation consideration. Therefore a brief description of some of the electrical characteristics of antennas will be sufficient for our purpose.

RADIATION RESISTANCE is an arbitrary term used to indicate the power radiated by an antenna. It is the amount of resistance which, if inserted in place of the antenna, would consume the same amount of power that actually is radiated by the antenna. The effectiveness of a given installation depends more upon a favorable impedance match between the antenna and the transmission line than upon power loss in the line.

ANTENNA POWER GAIN is a term used to compare an installed antenna with a standard antenna. A power ratio is sometimes used instead of power gain. In this case, either the ratio between the power in two antennas may be indicated, or the ratio of front to back radiation, may be represented.

DIRECTIVITY of the radiated field pattern is partially determined by the antenna. The E and H fields are spherical about an antenna's driven element. Fire control radars use reflectors or lenses to redirect and shape these fields into a narrow beam. By concentrating the spherical fields into a narrow beam, practically all the r-f energy is radiated in a desired direction. Since FC radars are interested only in single targets, the efficiency of the radar is greatly increased. In general, the larger the surface of a solid reflector or the larger the aperture of a feed horn, measured with respect to the r-f energy's wavelength, the greater the antenna's gain in the desired direction and the narrower the beam width. Hence the r-f wavelength and the antenna configuration both affect the radar's directivity.

The polarization of the r-f energy also affects the radar's directivity. The distinction between horizontally and vertically polarized waves is covered in the basic text. Horizontally polarized waves produce a narrow vertical field and a somewhat wider horizontal field. Vertically polarized waves produce a narrow horizontal field and a wider vertical field. Where an antenna has a parasitic element to shape and redirect the r-f energy, the polarization of the field in the horizontal and vertical planes is the same as that of the primary source.

SIDE LOBE SUPPRESSION

Side lobes of r-f energy exist around the major lobe in the radiated field, (fig. 10-4). Initially the r-f energy is radiated in a spherical wavefront. In most fire control radars these waves are reflected and redirected into a flat front wave form by a parabolic reflector. Some of the r-f energy spills over the reflector and forms a back radiation field. Back radiation is a power loss. Some r-f energy is reflected which will not be part of the major lobe. This energy forms the side lobes at various angles off the antenna axis.

Fire control radars employ high frequency r-f energy, and most of them have limited power. These features combine to make the side lobes extremely small. Furthermore, the tracking features of fire control radars reduce to practically nil the possibility of tracking an echo return from a side lobe.

Long range missile radars are relatively high powered, and consequently have side lobes which could present a problem. This is particularly true when the radar is used for missile

guidance. The missile enters the radiated field pattern at a short range. Thus there is a chance that it will enter and be influenced by a side lobe. This would undoubtedly confuse the missile and probably direct it away from the antenna axis (track line). If the missile is in one of the side lobes or the nulls between the lobes it may not receive enough energy at all times for use as a reference in the missile receiver. To eliminate these possibilities this type radar transmits a separate beam with a large pattern. Its field pattern overlaps the major field (capture beam) containing the major lobe and the side lobes. The separate beam is phase modulated to fill in the nulls and direct the missile toward the major lobe.

As you can see, the name side lobe suppression is a misnomer in that the side lobes are not actually suppressed but are compensated for. The elimination of side lobes in a field pattern is a design feature concerned mainly with antenna shape. Side lobe suppression circuits in the radar are used to overcome the results of the side lobes.

ANTENNA FEEDER SYSTEMS

Before considering the types of antenna feeder systems it is helpful to mention briefly some of the factors involved in coupling the transmission line to the antenna. The effectiveness of a radar's transmission system depends largely on impedance matching. If a good match is offered by the system throughout its operating band of frequencies, the efficiency of power transfer will be improved. The radio frequency is produced by the r-f generator, (magnetron or klystron). The generator's frequency will vary with a change in its load. This load, which is the impedance of the line and the antenna, has a characteristic impedance at its resonant frequency. A marked change in impedance results from any frequency variation from resonance. The transmission line should have a characteristic impedance that is equal to the antenna's impedance. Where this occurs, all the power will be absorbed by the antenna, and none will be reflected back down the line.

STANDING-WAVE RATIO

When there is an impedance mismatch at the end of a transmission line, standing waves are set up on the line. Standing waves cause losses

in the form of unwanted radiations from the line, and heat losses in the line.

The standing-wave ratio is a measure of the degree of mismatch between a line and its load. It can be expressed as a ratio of the maximum and minimum values of the current or voltage in the standing waves set up on the lines as

$$VSWR = \frac{E_{\max}}{E_{\min}},$$

or

$$CSWR = \frac{I_{\max}}{I_{\min}}.$$

The line approaches a matched condition when the standing-wave ratio approaches 1. A ratio somewhat above this figure is normally considered acceptable.

Correcting a Mismatch

High frequency and high voltage measurements are difficult to make. A practical method of detecting a mismatch is to measure the standing-wave ratio on the line. In this method either a calibrated variable dummy load is used to terminate the line, or the line's characteristic impedance can be varied by a calibrated adjustable tuning coupling. The load is varied or the coupling is adjusted until the standing waves, as measured by an r-f indicator, are minimized. When this occurs, the line is terminated in its characteristic impedance. Usually it is possible to match the line impedance to the antenna at only one frequency. The standing-wave ratio, however, will not become too high if the antenna is used over a small frequency range. When the radar operates over a range of frequencies, the line is matched at the center frequency.

DIPOLE ANTENNA

In early lower frequency fire control radars, the r-f energy was radiated by a dipole rather than a feed horn. The dipole located at the focal point of a parabolic reflector acted as a point source of energy. The theory of dipole antennas and their field patterns is covered in Basic Electronics. A small auxiliary reflector placed in front of the dipole directed the forward-going portion of the radiated energy back toward the large parabolic reflector. The presence of the

dipole and the auxiliary reflector has some blocking effect on the forward pattern.

As indicated in Basic Electronics, a dipole antenna has a characteristic electric length measured with respect to the wavelength of the transmitted energy. Hence a dipole antenna is highly resonant and frequency sensitive.

HORN TYPE RADIATORS

Horn radiators, like parabolic reflectors, may be used to obtain directive radiation at microwave frequencies. They are practicable in this frequency region because the dimensions, which must be large compared with the operating wavelengths, do not involve unduly large physical sizes. Because they do not involve resonant elements, they have the advantage of being usable over a wide frequency band.

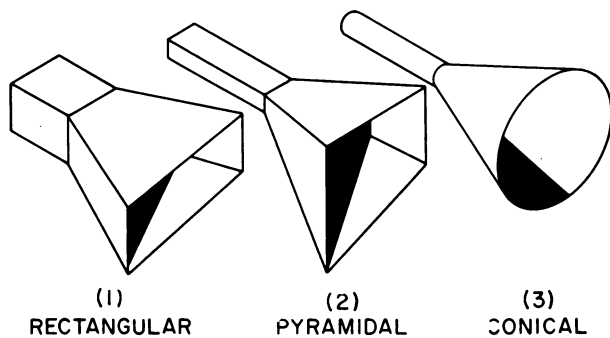
The operation of a horn as an electromagnetic directing device is analogous to that of acoustic horns. However, the throat of an acoustic horn usually has dimensions much smaller than the sound wavelengths for which it is used, while the throat of the electromagnetic horn has dimensions that are comparable to the wavelength being used.

Horn radiators are adapted readily for use with waveguides because they serve both as an impedance-matching device and as a directive radiator. Horn radiators may be fed by coaxial or other types of lines.

Horns are constructed in a variety of shapes (fig. 10-12). The shape of the horn, along with the dimensions of the mouth, largely determines the field-pattern shape. In general, the larger the opening of the horn, the more directive is the resulting field pattern. An aperture of approximately five wavelengths in the long dimension produces a radiated lobe of approximately 30°.

PHASED ARRAY

At the present time the directivity of fire control radars is obtained by a parasitic reflector (not directly connected to the transmission line), and a point source which initially radiates the energy. New approaches to obtain greater antenna efficiency and directivity are being developed. One such approach offering promising possibilities is the phased array antenna. This type antenna has been used in radio systems for many years. Recent developments in the microwave field have made the



13.41

Figure 10-12. —Horn radiators.

advantages of this type antenna available at radar frequencies. The principles of antenna operation are similar in radio and radar. Thus we can discuss radio phase array antennas to provide background information for radars using phase array antennas.

Antenna Arrays

Driven arrays have smaller losses than parasitic arrays, and they retain the narrow-beam characteristic of the parasitic array. If a number of driven half-wave antenna elements are so positioned with respect to each other that energy arriving at a point from the individual elements will add in certain directions and cancel in other directions, then the antenna system is directional.

Signals arriving at a point from a number of different sources may contribute to or subtract from the net effect. By properly phasing the energy fed to the antenna elements, and by properly locating the elements, the energy may be made to add in the desired direction and to be out of phase, or oppose, in the undesired direction.

Driven arrays are usually made up of a number of half-wave dipoles so positioned and so phased that the desired directional pattern will be achieved. Figure 10-13A shows a simple antenna array consisting of two horizontally mounted elements each a half wavelength long and fed in phase. The resulting radiation is in a direction at right angles to the plane containing the antenna conductor.

Three- and four-element arrays are shown in figure 10-13, B and C, respectively. The field pattern of each array is shown beneath the array. Note that the beam becomes sharper

as the number of elements is increased. If a still narrower beam is desired, additional units may be added either horizontally (side by side) as shown, or vertically (one above the other in the plane of the antenna), depending upon the direction in which it is desired to restrict the radiation. The field patterns of the antennas in the figure are bidirectional. Unidirectional patterns may be obtained with a parasitic reflector mounted behind the driven antenna elements.

Thus far we have discussed conventional array antennas. In a radar system using this type of phase array antenna, we would increase the number of driven elements. The antenna feed system would be designed so that the phase of the r-f energy could be varied between the elements. The antenna is stationary; but varying the phase of the feeds between the elements, the radiated field pattern is rotated.

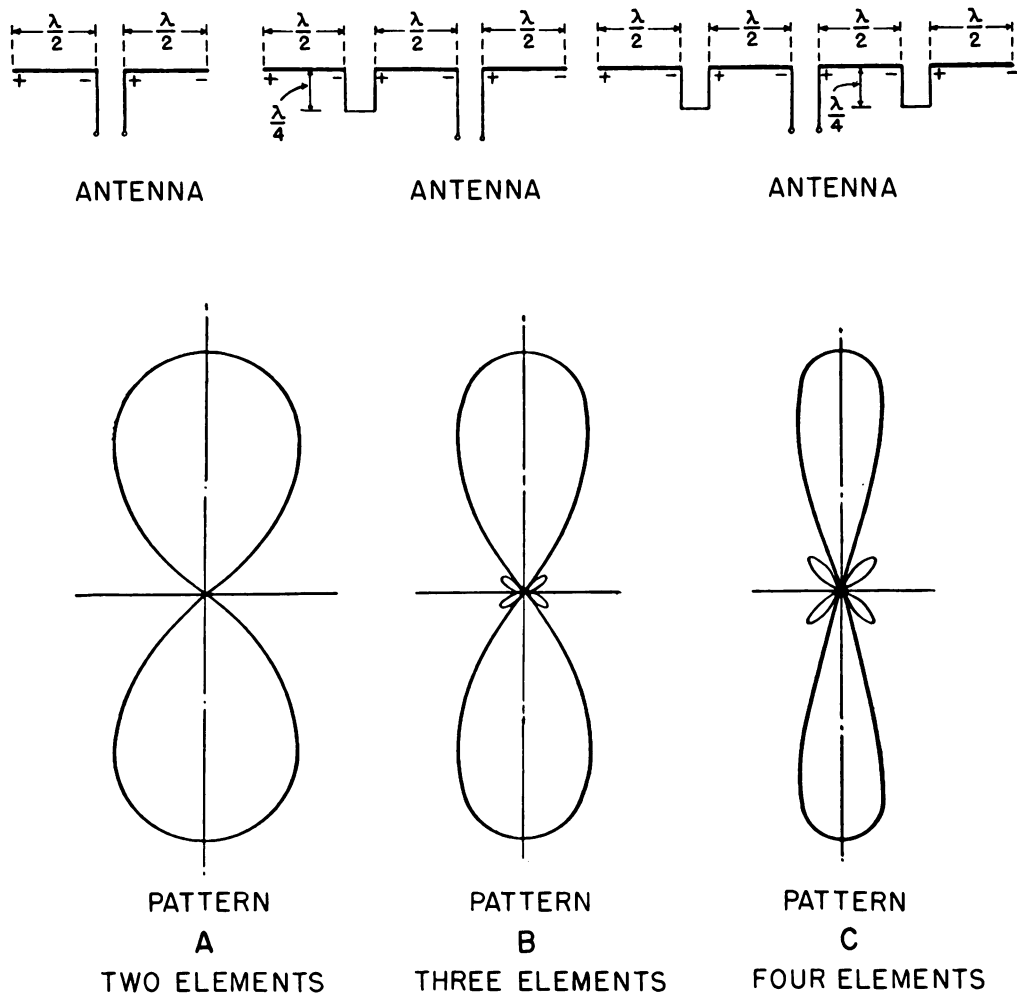
DIRECTIONAL INFORMATION

Microwave radar, with its narrow beam, is an excellent instrument for finding the coordinates of a target. In a previous course of this series we discussed the principles of sequential and simultaneous scan; and the advantages of lobe switching, conical scan, and monopulse scan. The use of one or more types of scan in a radar set is governed by the radar's application. As you know, fire control radars normally concentrate on only one target at a time. Initial detection of the target requires radar coverage of a relatively large area. Upon detection, the area is greatly reduced. Thus the scanning process is changed between the different modes of radar operation. We will first discuss a conical scanning system and then a monopulse scanning system.

CONICAL SCANNING

Conical scanning is a form of sequential scanning. We will use a pulsed type radar as representative of a conical scan system. (The radar is pulsed for range determination; pulsing is of no value in scanning.) The fact that the radar is pulsed tells us that the r-f energy is radiated in short bursts. The antenna has a parabolic reflector to shape the beam. The antenna feeder system is terminated by a backward radiating feedhorn.

The simplest way to produce a conical scan is to offset the feedhorn slightly from the focal point of the reflector. The feedhorn is nutated



1.256

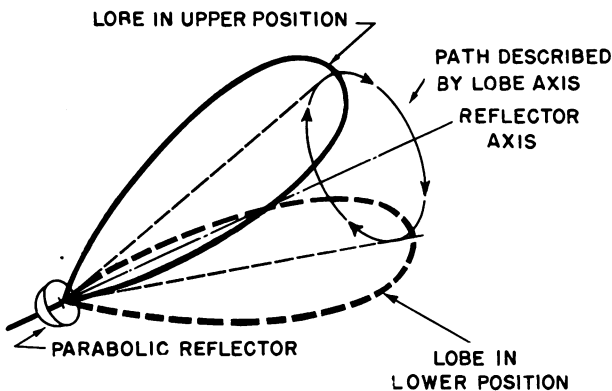
Figure 10-13. —Horizontal colinear arrays and field patterns.

by a scanning motor. For our system, which is a simplified one, we will use a speed of 30 rps (revolutions per second). The offset of the feedhorn produces a beam which is offset from the axis of the reflector, so that nutation of the feedhorn results in conical scanning. The beam axis describes a cone in space around the axis of the reflector, (fig. 10-14). In this way the beam explores the space in the vicinity of the target. The shape of the cone is determined by the amount of feedhorn offset from the reflector axis and the shape of the reflector.

The echo signal received from a target which lies on the axis of the reflector has the same amplitude for all positions of the beam. If the

target moves away from the reflector axis, the echo signal varies approximately sinusoidally with the rotation of the beam. As the axis of the beam nears the target the echo signal increases, and as the axis of the beam moves away the echo decreases. Hence the target produces an error signal that reveals the target's direction with respect to the axis of the antenna. The phase of the signal variation indicates the direction of the target from the reflector axis. The magnitude of the signal variation indicates the target's displacement from the reflector axis.

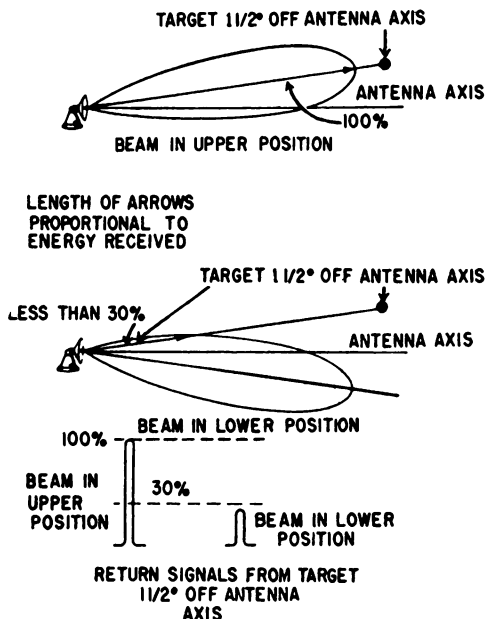
The amplitude variation of a target echo, when there is a pointing error, is caused by the



33.113

Figure 10-14.—Antenna beam during conical scan.

nutations of the feedhorn. Thus there is one position in each cycle of nutation at which the echo from the target is strongest, and one at which it is weakest (fig. 10-15). To correct the pointing error, the antenna must be moved toward the point of the strong echo return. To determine this direction, the position of the feed horn with respect to the reflector axis must be known



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Figure 10-15.—Return signals from target $1\frac{1}{2}^\circ$ off antenna axis.

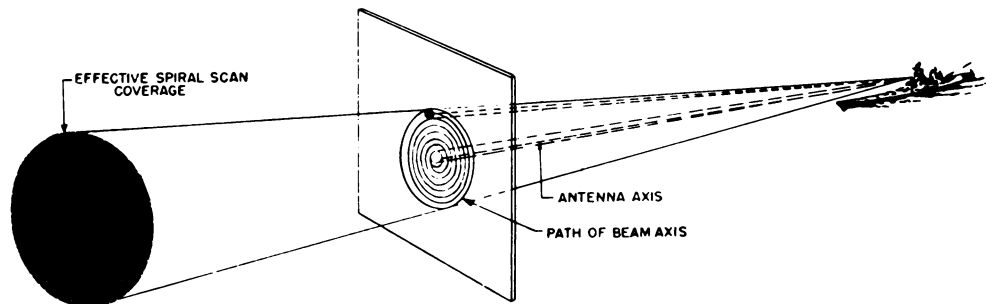
at all times. Furthermore, feed horn displacement must be resolved into two components 90° apart. One component represents bearing displacement and the other elevation displacement; these are the axes of antenna motion. In the antenna scanning mechanism a two-phase reference generator is geared to the scan motor drive. The generator's outputs are two sinusoidal reference voltages 90° out of phase. The frequency of the reference voltages is the same as the nutation frequency—in the present example 30 cycles per second.

Tracking is accomplished by a continuous comparison and balancing of the amplitude modulated echo return. The reference voltages are used as a measure of feed horn position as it varies with time. The tracking system continuously measures the relative strength of the echo return at each feed horn position, to determine which way the antenna must be moved to eliminate a pointing error. When the axis of the reflector points directly at the target, the echo signals have the same amplitude for every position of the beam as it nutates about the reflector axis.

To decrease the time required for the radar to acquire a target, the scan pattern is changed from conical to spiral. In spiral scan, the pattern covers a much larger area (fig. 10-16). This is accomplished by varying the feed horn offset from the reflector axis. The offset is continuously varied as the feed horn is nutated. As the feed horn displacement is increased, the field coverage increases. The feed horn's nutation speed is the same as in conical scan but the field is larger. Hence the amplitude of the reference voltage, which represents feed horn position, must be varied in proportion to the varying amount of feed horn displacement.

In our system, a cam and bell crank arrangement varies the displacement. A synchro control transformer is geared to the cam follower. The reference voltages from the generator are the inputs to the stator of the control transformer. The CT's rotor output is proportional to feed horn displacement. The output is used directly for bearing, and is shifted 90° in phase for elevation.

There are other types of sequential scanning—circular and elliptical for example. And as is usually the case, the scan mechanisms vary between radars. Fortunately, all the scanning systems have the same requirements and similar principles. Conical scan is obtained by a constant offset of the feed horn from



92.94

Figure 10-16. —Antenna beam during spiral scan.

the focal point of the reflector. This type of scan is used for tracking. A larger search pattern is obtained by varying the amount of feed horn offset. In both types of scan, the feed horn is nutated.

MONOPULSE

Monopulse is a simultaneous scanning system capable of obtaining the range, bearing, and elevation of a target from a single pulse. Hence, the name mono (one) pulse. In the monopulse system we are considering here, the radar radiates into space a single beam whose axis coincides with the antenna axis. Normally, with a single beam fixed with respect to the antenna, a target could move a substantial distance from the antenna's axis before the radar's tracking system would detect a displacement and react. To track a moving target, an error signal is necessary. Error signals are obtained by comparison. In sequential scanning the error signal is obtained by comparing the strength of echo returns from successive pulses. In monopulse systems the pulse is divided into four separate parts in the waveguide system. The four parts are radiated by separate feed horns, and are combined by the antenna into a single beam. Returned echoes are divided back into four parts. The relative strength of the parts are compared to obtain target position with respect to the antenna axis (fig. 10-17).

The heart of this monopulse system is called the microwave comparator. It consists of four

feed horns, four hybrid rings, and connecting waveguide sections. To understand the operation of the monopulse comparator, a knowledge of waveguide theory is needed. This, plus the four rules that follow—rules for "T" junctions in waveguide systems—will be enough background information to enable you to trace out the energy paths through the antenna system during transmission and reception.

Rules for Hybrid Ring Junctions

Hybrid ring junctions are often given a more colorful name: ratrace. These rings are used to add, subtract, and split up r-f energy. They also provide switching of energy into appropriate channels. The hybrid ring junctions consist of a waveguide ring with four arms projecting from it. Each arm can be connected to a waveguide section. In the figures of hybrid ring junctions, the symbols delta (Δ) and sigma (Σ) placed by an arm stand for the difference and the sum respectively, of signal amplitudes.

The principle of operation of a hybrid ring can be summarized very briefly by the following rules, which are illustrated in figure 10-18.

1. A signal applied to a Σ (sum) arm will split and leave the ring at two adjacent arms. The output signals will be equal in amplitude, but 180° out of phase with one another.

2. A signal applied to a Δ (difference) arm will split and leave the ring at two adjacent arms. The two output signals from these arms are equal in amplitude and in phase.

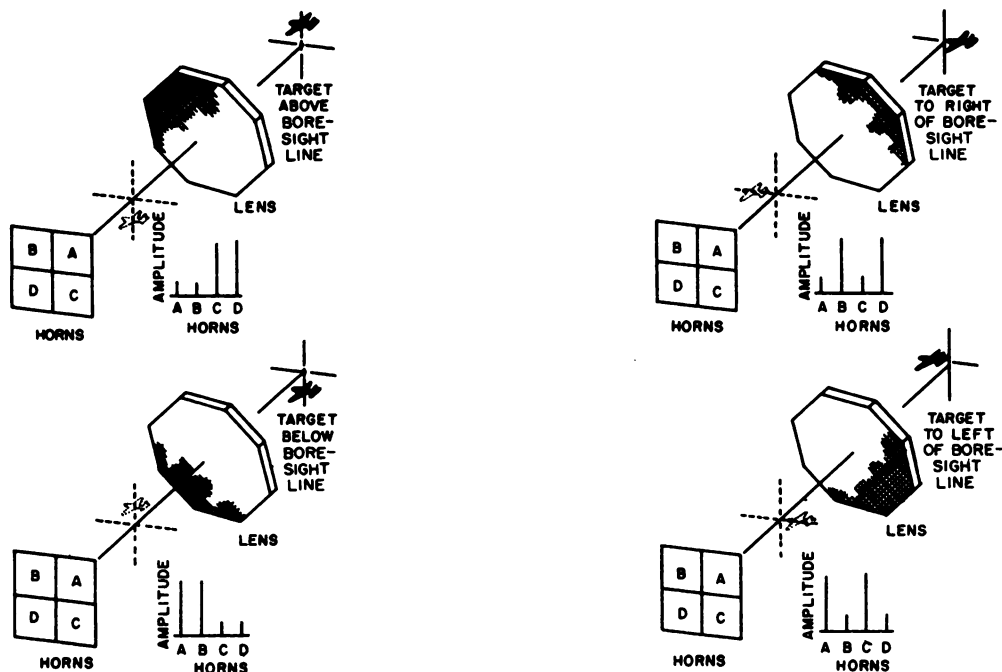


Figure 10-17.—Amplitude changes of received energy with target position.

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3. If in-phase signals are applied to two opposite arms, the output of the adjacent Δ arm will be proportional to the sum of the input signals. The output of the Σ arm will be proportional to the difference of the input signals.

4. If 180° out-of-phase signals are applied to two opposite arms, the output of the adjacent Δ arm will be proportional to the difference of the input signals. The output of the Σ arm will be proportional to the sum of the amplitudes of the input signals.

Monopulse Comparator Operation

A simplified schematic of the comparator is shown in figure 10-19. To find out how it works, first, let us trace out the energy paths during transmission. Transmitter energy enters the summation arm of HY-1. According to rule 1, the signal splits and leaves the ring at the two adjacent arms. These two signals have the same amplitude, but are 180° out of phase. Then the signals are fed to the summation arms of hybrid rings HY-2 and HY-3. The waveguide lengths between HY-1 and HY-2, and HY-1 and HY-3 are equal; hence the signals enter the rings simultaneously. Again keeping in mind

rule 1, the signals in HY-2 and HY-3 divide their energy equally and out of phase with each other. The energy, now divided into four separate signals, is sent to the horn cluster. By varying the waveguide sections between the hybrid rings and horns, the separate signals will arrive at each horn in phase with one another. The energy radiated from the horns combines to form a single wavefront. The radiated energy is focused into a narrow circular beam by the lens antenna. Energy does not pass through the difference arms of HY-1, HY-2, and HY-3 because the signals are cancelled at these junctions by proper waveguide matching. If energy were allowed to pass through these arms, it would burn out the mixer crystals, and possibly the receiver.

Echo returns are focused by the lens into the four horns. The amount of energy entering each horn is determined by the position of the target with respect to the antenna axis. Phase inversion of the energy takes place due to the lens. Returned energy is combined in the four hybrid rings of the comparator. The comparator compares the amplitude of the energy in each horn, and produces a sum signal and two difference signals. The sum signal is used for

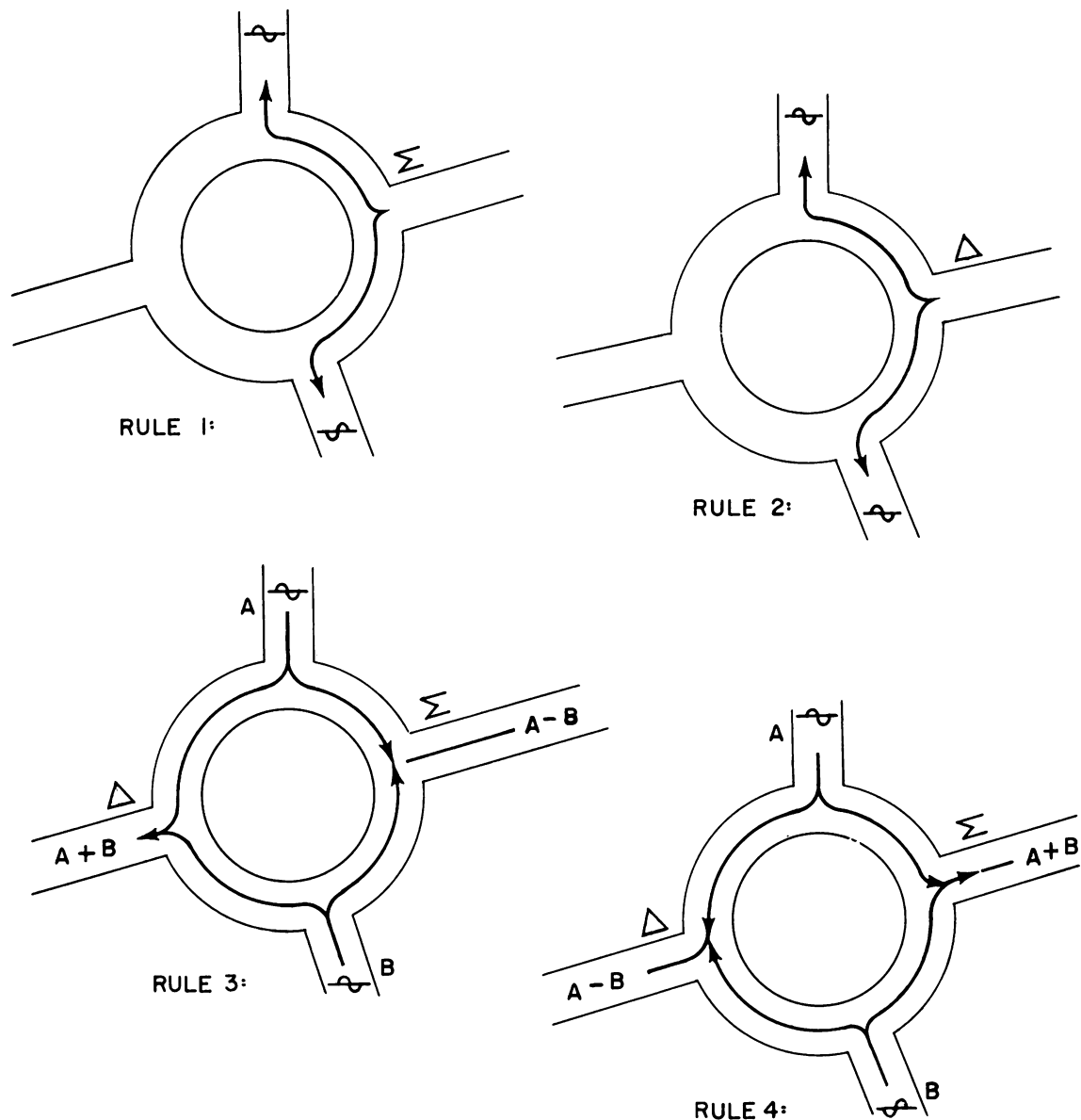


Figure 10-18.—Hybrid ring junctions.

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ranging and also provides a reference for the elevation and traverse tracking channels.

The sum or range signal is composed of signals from all four feed horns added together in phase. Since the radar's range system is only interested in the presence of the target in the beam, and not in the target's relative position within the beams, the sum of all the energy received is used in ranging to ensure maximum detection capability. The sum signal is also

used as a phase reference for the amplitude difference signals which are the elevation and traverse error signals. The sum signal is obtained in the following manner. The energy from horns A and B is applied to the ring HY-2. These signals are 180° out of phase with each other. (Remember that the waveguides are different between these two horns and the ring.) Now, according to rule 4: the output of the Σ arm will be proportional to the sum of

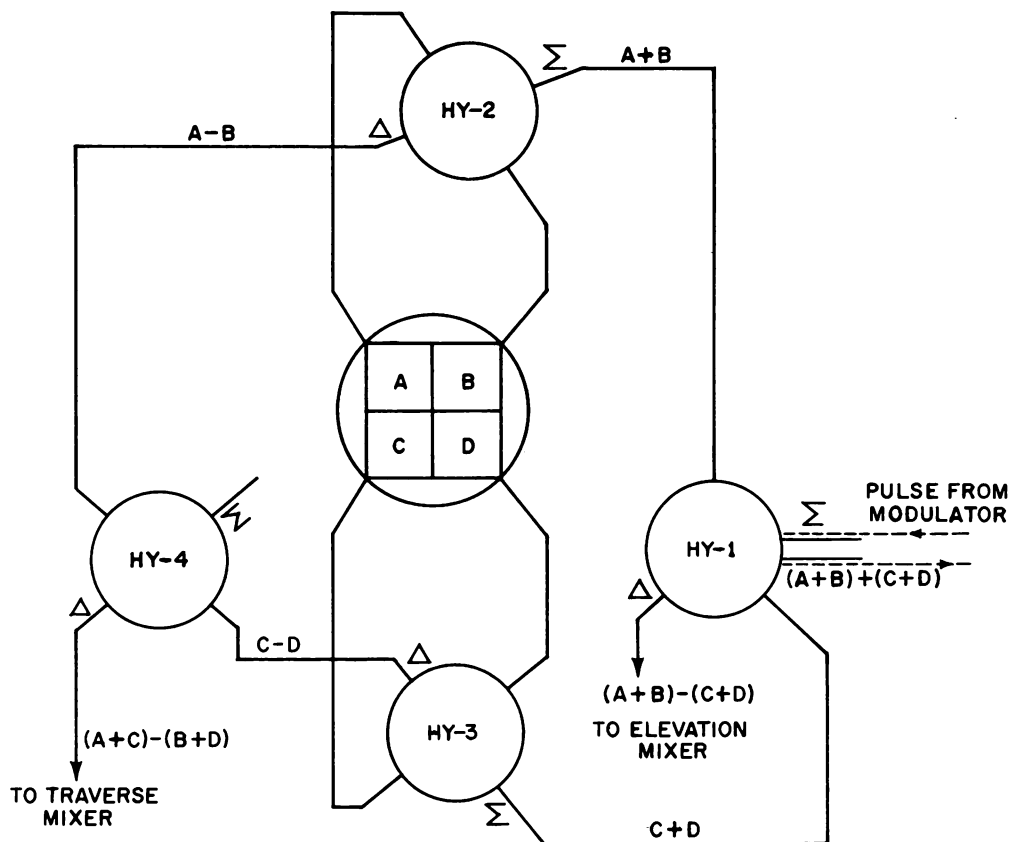


Figure 10-19.—Microwave comparator.

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the amplitudes of the input signals, $(A + B)$. The energy from horns C and D is applied to the ring HY-3. The action here is the same as for ring HY-2. The output of the Σ arm of HY-3 is $C + D$. The signals $A + B$ and $C + D$ are 180° out of phase with each other and are applied to the ring HY-1. The output of the Σ arm of HY-1 is the sum of both signals or $(A + B) + (C + D)$. This signal is sent to the radar receiver.

The traverse difference signal is made up of signals from horns A and C added in phase, and from horns B and D added in phase, but the latter combination of energy is 180° out of phase with the energy from A and C. The energy from horns A and B enters ring HY-2 and, in accordance with rule 4, the output from the Δ arm is the difference of the input signals. This signal $A - B$ is sent to HY-4. The energy from horns C and D enters ring HY-3. The output from the Δ arm of the ring is $C - D$, which is sent to HY-4. The output of the difference arm of HY-4

is the difference between the two signals, which can be stated as $(A + C) - (B + D)$. Note that this statement determines the difference in energy received from the left-hand horns, A and C, and from the right-hand horns, B and D. This signal is then sent to the traverse mixer in the receiver.

The elevation difference signal consists of the signals from horns C and D added 180° out of phase with A and B signals: $(A + B) - (C + D)$. This signal is arrived at by using the Σ arm of HY-2 and HY-3, and the Δ arm of HY-1. Note that this signal compares the energy received in the upper horns A and B with that received in the lower horns C and D. The signal is sent to the elevation mixer in the receiver.

The elevation and traverse difference signals are compared in the radar receiver with the sum or reference signal. The output of the receiver may be positive or negative pulses, the amplitude of which is proportional to the displacement of the

target from the boresight (beam) axis. The polarity of the output pulses indicates the direction of the displacement. Of course if there is no angle tracking error, the output is zero.

This monopulse system provides direct amplitude comparison of the r-f signals. Hence noise generated by the local oscillator and produced in the i-f section of the receiver has less effect on the angle tracking system.

TARGET SELECTION

As previously stated, fire control radar is normally used to track a single selected target. Where multiple targets are in close vicinity to each other, range as measured by the radar is used to select the correct target. Before the angle tracking system will function, the target must be gated in range. In both the sequential and monopulse systems described, the r-f energy is radiated in pulses of short duration. In conventional pulsed radars the pulse repetition rate, (PRR), is low and only one pulse is within the range measuring limits of the radar at any given instant. In pulsed doppler radars the PRR is high and many pulses are within the ranging limits of the radar at once. The differences in obtaining range measurements in these two types of radars is covered in the FT 2 course.

In either type radar the antenna arrangement to obtain angular directional information is as described. Either scan system can be used with either type radar. Monopulse scan, however, is usually found in pulse doppler radars.

Continuous-wave (CW) radars require separate transmission and reception antennas. Hence this type radar is normally not used in fire control systems for target tracking information. The CW feature, however, makes it an ideal illuminating radar for missile homing systems, in which case the receiver is in the missile.

PULSE COMPRESSION

Pulse compression is used to improve the radar's target resolution and the signal-to-noise ratio in the receiver. As you know, a pulse doppler radar's transmitted pulse is relatively long. This improves the power output of the radar since the pulse energy is equal to the pulse power times the pulse length. The long pulse is also necessary to obtain a reconstructable doppler frequency in the receiver. Here the target's presence and also its relative position in the beam is determined by the amplitude of the

echo returns. The length of the echo return is equal to the length of the transmitted pulse. The long pulse is not necessary in the receiver. Still we do not wish to lose any of the returned energy.

To improve target resolution and to retain the maximum amount of returned energy a pulse compression network is placed in the i-f section of each of the tracking networks (range, traverse, and elevation). The pulse compression is similar in each network. These networks compress the input pulse into a sharp spike that contains almost all the energy in the input pulse. A pulse compression network consists of capacitors and chokes arranged as a time delay filter. The arrangement is such that the phase shift in the filter is proportional to the square of the input frequency. A filter with this phase-frequency characteristic produces a time delay proportional to the frequency of the applied signal. Hence to vary the time delay so as to compress the pulse into a spike, the frequency of the input is varied. Let's see how this is done.

The energy within the transmitted pulse is frequency modulated. This energy sweeps either from high to low or low to high within a frequency band. We will consider only the high to low sweep in the discussion. During this sweep the local oscillator frequency is above the transmitted frequency (the local oscillator would be below for the low to high sweep). Energy returned from a target has the same frequency modulation as the transmitted energy. The returned energy is mixed with the local oscillator frequency. Since the local oscillator frequency is higher than the returned frequency, the frequency difference, or intermediate frequency, is lower at the beginning of the pulse than it is at the end of the pulse. This wide pulse is the input to the pulse compression network. The lower intermediate frequency at the beginning of the pulse takes a longer time to pass through the filter than the higher frequency at the end of the pulse. Since the frequency sweep is linear, the time delay of the pulse is linear. Consequently the energy builds up in the filter and the output pulse is compressed with respect to time. Except for the small losses due to the filter components, the output energy is equal to the input energy. Noise entering the filter does not have the frequency sweep required for compression, and is therefore attenuated.

As you know, radar measurements are made with respect to time, and the synchronizer trigger is used to coordinate the various time factors in the radar. The time of the transmitted pulse is normally considered as zero time. The time delay in the pulse compression network has offset the receiver's time from the transmitter's time.

Range, for example, is computed by measuring the delay between the range trigger and the range video. Therefore, by delaying the range trigger the same amount as the range i-f pulse was delayed by the pulse compression network, we can compensate for the apparent increase in target range. A delay network is inserted in the synchronizer trigger circuit to compensate each unit where pulse compression has offset the time factor.

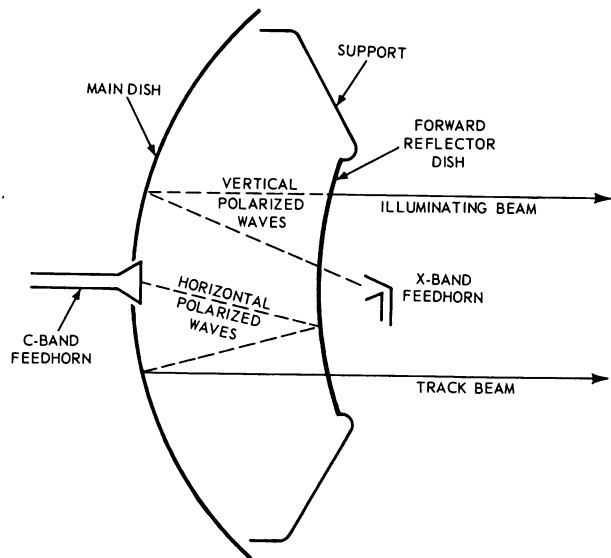
MULTIPLE-BEAM ANTENNAS

Missile systems require more than one radar beam. For example, a system controlling a beam-riding missile requires a target tracking beam, a missile guidance beam, and a missile capture beam. A system controlling a semi-active homing missile requires a target tracking beam and a target illumination beam for missile homing; plus, if the missile beam rides during part of its flight, capture and guidance beams.

Since the functions of the beams vary, their characteristics may vary. This being the case, many installations take advantage of this fact and use one antenna assembly to radiate more than one beam. For example, a system used to control a homing missile needs a target tracking radar and an illuminating radar. These radars

have separate receivers. The track radar's receiver is aboard ship, while the illuminating radar's receiver is in the missile. Therefore the two radars can use different frequencies. The track radar may be in the C-band and the illuminating radar in the X-band.

The Cassegrainian antenna shown in figure 10-9 is shown again in figure 10-20 with the illuminating beam added. Note that the beams are cross polarized. This greatly reduces the amount of radiation from one feed horn that can enter the other feed horn. In addition, filters inserted in the radars will effectively filter out the frequency of the other beam.



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Figure 10-20. —Multiple beam antenna.

CHAPTER 11

MAINTENANCE AND ADMINISTRATION

INTRODUCTION

Up to now, in your career as a fire control technician, the part you have played in the maintenance programs of your ship has been one of the "worker." That is, your main concern has been doing the routine maintenance required for your equipment, running the routine tests, and assisting with the repair work.

Now, as a senior petty officer it will be your job to administer the various maintenance programs, analyze tests results, and take corrective action to keep your equipment in A-1 condition.

As you have seen in chapter 3, analysis of computer tests (static and dynamic) requires a thorough knowledge of the "family tree" of each quantity. To analyze errors in these tests it is necessary to go back through the "tree" to the different branches that make up the entire quantity to find where the errors are developing.

In chapter 6 analyses of the errors that may be encountered in battery alignment are discussed, and suggestions as to corrective action necessary to correct these errors are given.

In chapter 13 you will find a complete discussion on the use of the dynamic testers, dummy directors, and error recorders. There is also a section on how to analyze dynamic test results.

In our modern fire control equipment, electronics plays a most important part. Analysis of troubles in electronic equipment depends largely on your knowledge and use of the various types of test equipment such as oscilloscopes, meters, and calibrators. The job of finding trouble in a piece of electronic equipment depends largely on checking voltages, currents, and wave forms against known standards (for example POMSEE), or against readings taken when the equipment was operating at peak performance.

Good analysis of any test errors or troubles in your equipment depends on your knowledge of

the equipment, and your ability to use the test equipment available to you.

It will be your duty, as a senior petty officer, first to instruct your junior petty officers and strikers in the proper methods of conducting routine maintenance and tests. Secondly, you must know your equipment thoroughly to be able to analyze test errors and trouble. And you must be able to take the corrective action needed to put your equipment back in operation with a minimum of "down time."

To be an effective petty officer you must also have a certain amount of administrative ability. Some of this may be natural aptitude, but much can be learned. Administrative ability is an important part of leadership. It includes the arts of organization, management, and human relations. A good administrator can grasp the overall plan, fill in details of the plan, determine his place in it, and carry out his part of it with the help of his men. A course which you have completed, Military Requirements for Petty Officer 3 & 2, NavPers 10056-A, discusses at some length the qualities you need to become a leader. More emphasis is placed on the planning responsibilities of the petty officer in Military Requirements for Petty Officer 1 & C, NavPers 10057-A. It devotes a whole chapter to administrative duties, and in related chapters discusses them in particular areas or fields. Keeping records and making reports are important parts of those duties.

SHIPYARD AND TENDER AVAILABILITY

The equipment and hull spaces under your cognizance must be kept in good working order at all times. The weapons officer is responsible for all repair work in the weapons department and must be kept informed (through your division officer) of all required repairs as well as the progress of current repair work. The weapons

officer ensures that ship's force does as much as possible and that all work is accomplished AS REQUIRED. Overall repair and overhaul work, however, is under the cognizance of the engineer officer. If help must be obtained from the engineering department, the requirements must be brought to the attention of appropriate engineering department personnel.

The engineer officer is the key man in planning and carrying out shipyard overhauls and tender availabilities, for accomplishing authorized alterations, and sometimes for obtaining outside assistance to effect emergency repairs. The engineer officer's chief aid for overhauls and repairs is the CSMP. The CSMP is also the basis for scheduling repairs and serves as a complete record of what was accomplished.

Strangely enough, the primary factor in unsatisfactory shipboard repairs is the lack of knowledge of how to get the repairs scheduled and accomplished on time. Experience shows that an improperly prepared work request usually produces inadequate repair work. Because the division leading petty officer usually makes up the initial work request, his knowledge of correct procedure is indispensable to satisfactory repair work.

At some time during an overhaul, your division officer may be away from the ship for one reason or another. At such times you will be acting division officer. You therefore must be "in on" all of the preliminary planning in order to properly supervise repairs in your division officer's absence.

It is not enough for you merely to be in on the preliminary planning for formal repair periods; you must also be able to follow through during the entire repair period on all division work, for much of the repair work will not be done by your men.

Last, but no less important, you should have a good understanding of correct repair procedures so that you can get your division repair and maintenance work done in the in-port period and have sufficient time left for training your men and for leave.

TENDER AND YARD WORK

Few periods within the life of a ship affect operational capabilities as much as the shipyard overhaul. In order that the primary objectives—the best possible overhaul of the

ship—may be accomplished, department heads make preparations and plans well in advance of entry into the shipyard. The tender period is similar to the yard overhaul period in that plans and preparation usually must be accomplished in the same manner.

REPAIRS

Repairs to ships are generally accomplished by the ship's force, repair ships and tenders, and naval shipyards. Individual ships should make every effort toward self-maintenance in order to reduce the number of overhaul periods.

Your main problems are to discover what repairs are necessary and to determine which equipments are not performing satisfactorily. Then you must prepare work requests for these repairs.

REGULAR OVERHAUL

CNO assigns ships regular overhaul periods based upon recommendations of the fleet and type commanders concerned. The length of the overhaul and the interval between overhauls varies with different types of ships. Generally, large combatant ships are scheduled to receive a 3-month overhaul about every 2 years.

The basic purpose of naval shipyards is to render service to the fleet. To carry out this function more effectively, each ship in the fleet is assigned a home yard by the Chief of Naval Operations. A home yard is defined as the shipyard at which a ship usually overhauls.

REPAIR SHIPS AND TENDERS

The chief difference between repair ships and tenders is one of function. Repair ships are concerned primarily with maintenance in support of various types of vessels or craft. Tenders, on the other hand, support in all respects the specific types of ships to which they are assigned. Thus, on a repair ship there are general maintenance facilities for a number of types of craft and stocks of commonly used repair parts. Tenders have facilities for a single type of ship. The material items are peculiar to that type and other similar ships in the same squadron. In addition, a squadron of ships depends on the tender for ammunition, general stores, medical facilities, and (often) quarters.

REPAIR PROCEDURES FOR REPAIR SHIPS AND TENDERS

Ships are scheduled for routine overhaul periods alongside repair ships or tenders at certain intervals of time. These intervals vary according to the types of ships. Small ships usually have a tender overhaul period every 6 months. Normally, the time that a ship spends alongside a tender or repair ship is about 2 weeks. These tender overhaul periods usually are planned far in advance and depend upon the quarterly employment schedule of the ship. Ordinarily, the ship knows well in advance when it is to go alongside a tender or repair ship for a routine overhaul period.

When a ship receives its employment schedule, it can begin preparations for the overhaul period. An inspection is made to see that the Current Ship's Maintenance Project is up to date in all respects. A CSMP card is used in preparing work requests for repair ship accomplishment. The work requests are typed and arranged in order of priority within their respective categories, i.e., mechanical, electrical, and hull. In tender and repair ship overhauls, alterations marked for accomplishment by forces afloat are included in the work request list.

Work requests (with the required number of copies) are forwarded to the type commander or his representative. The staff officer handling material and maintenance screens the work requests. Most of the ship's overhaul work list items are approved or authorized. Some items are revised so that ship's force must accomplish most of the work involved. And sometimes, the ship may have to furnish more detailed information on certain work requests. The amount of corrective action taken by the reviewing staff officer depends upon how well the work requests are written and if they follow established policies or procedures. Upon the completion of this screening, the ship's work requests are forwarded to the repair ship or tender.

The ship must prepare the work requests in sufficient time to permit all major work items to reach the repair ship not less than 30 days in advance of arrival alongside. Where necessary, supplementary work requests should reach the repair activity not less than 10 days in advance of arrival. This procedure may vary somewhat for different naval organizations, but these are the usual requirements.

ARRIVAL CONFERENCE

When a ship comes alongside for an assigned routine availability, an arrival conference usually is held immediately. Representatives of the ships, of the repair department, and normally of the type commander are present at the conference. The relative needs of the ships and the relative urgency of each job are settled. Jobs that have been stated indefinitely are defined specifically. The arrival conference serves to clarify all uncertainties for the repair department, which received and studied the work requests in advance.

WORK REQUESTS AND JOB ORDERS

The term "work requests" and "job orders" sometimes are used interchangeably. This is not technically correct, however, because there is a difference in meaning of the two terms. Work requests are made up by the ship and forwarded through proper channels to a repair ship or naval shipyard. When a work request is approved by the repair activity, it becomes a job order. Naval shipyards, however, issue their own form of job orders when the work requests are approved. In either situation, a job order is an approved work request. The approval, of course, has to be made by the repair activity.

GETTING THE WORK STARTED

As soon as the work requests are approved at the arrival conference, jobs requiring delivery of material or parts to the tender shop should be started.

The sooner you get the repair jobs to the shops, the quicker the shop crew can get started with their work. Equipment not needed for the operation of the ship may be disassembled in advance so that the defective parts can be delivered to the shop as soon as the work requests are approved.

All material delivered to the tender should be properly tagged and identified. Metal tags secured with wire are preferred. Data on the tag should include the following information: the number (and name, where practicable) of the ship, the department, the division or space, and the job order number. (The tender assigned number should be used when possible.) Additional information may be included as necessary. Reference material, such as blueprints and equipment technical manuals, should have the ship's name and number on them.

SHIP-TO-SHOP JOBS

Many of the repair jobs are designated by the ship or approved by the repair activity as "ship-to-shop" jobs. This means that the ship's force delivers the equipment to the shop at the repair activity.

Before the equipment is delivered to the repair shop, to the extent necessary, it is disassembled and the parts identified and tagged. When necessary, blueprints are also delivered. At the repair shop, the shop supervisor checks on the job and gives an approximate date of completion. When the equipment is repaired, the ship's force picks it up at the shop and takes it back to the ship to reassemble and reinstall it. Inspections and tests are then made to see that all conditions are satisfactory.

CHECKING PROGRESS OF REPAIR JOBS

The Fire Control Technician should always keep himself informed of the progress of all repair work for his spaces and equipments. The repairs that are being accomplished on board his ship can be checked on easily by discussing them with the petty officer in charge of the repair.

The method of checking progress of work in the ships requires some planning and coordination between ones own ship and the tender. It must be remembered that the personnel in the tender shops are busy with their repair work. Consequently, the method used in checking progress should be one that does not interfere with personnel working in the shops.

Some tenders and repair ships have a chief petty officer who acts as a ship's superintendent. His duties are, in general, as follows:

1. Acting as liaison officer between the ships alongside and the tender in regard to repair department jobs.
2. Acting as a coordinator of shop work for the assigned ships.
3. Reporting daily to a representative of the commanding officer of the ship to ensure that the work is progressing satisfactorily as far as the ship is concerned.
4. Maintaining a daily progress report or chart that indicates the percent completion of each job, the availability of plans, equipment technical manuals, and the availability of material required for each job.
5. Notifying the ship to pick up completed material on the tender.

6. Notifying ship's personnel to witness tests occasioned by work performed on machinery, compartments, etc.

7. Obtaining signatures from officers concerned if a job order is canceled.

8. Securing signatures from officers concerned on completion of job orders.

Thus, where a tender or repair ship provides a ship's superintendent, the progress of work on the tender can be checked easily, because the ship alongside is furnished the necessary information by the superintendent.

Where a ship's superintendent is not provided, it is advisable that the ship appoint a senior petty officer to perform similar duties for the division or the weapons department.

A progress chart should be obtained and filled out for all the jobs to be accomplished during the repair period. This chart should be kept up to date to indicate the status of each repair job.

The main purpose of checking progress of repair work is to see that (1) jobs are not delayed unavoidably, (2) no job is overlooked or forgotten, and (3) all jobs undertaken are completed satisfactorily by the end of the repair period.

SHORE-BASED REPAIR ACTIVITIES

Shore-based repair activities include naval repair units under the management control of BuShips or CNO, and commercial ship repair yards under contract to the Navy.

ORGANIZATION

No standard organization is applicable to all shore-based repair activities. Although all have similar organizations, the details depend upon various conditions. Some shore-based repair activities have a more or less abbreviated form of naval shipyard organization. Others adapt their organization directly from that of a repair ship or tender. The major difference between the two types of organization lies in the existence or nonexistence of separate planning and production departments. An abbreviated naval shipyard organization has separate planning and production departments. In the repair ship or tender organization, both functions are accomplished by the repair officer and his assistants. The larger the shore-based activity, the more it conforms to a naval shipyard type of organization.

PROCEDURE FOR EFFECTING REPAIRS

The procedure for effecting repairs at a shore-based repair activity is similar to that of a repair ship or tender. Work requests proceed from the originating ship to the type commander's representative for screening. Then they go to the local service force representative, and finally, to the repair facility.

From time to time your ship will be temporarily in places where shore-based repair facilities are available. With the approval of the type commander (who furnishes the funds for repairs), emergency and voyage repairs may be accomplished, depending upon the time available.

PLANNING AND PREPARATIONS FOR SHIPYARD OVERHAUL

In addition to the preparation of the shipyard work list (discussed later) the engineer officer, weapons officer, and other department heads provide for the preparation of or make plans to cover the following:

1. Ship's force work.
2. Tender work list (if a tender is assigned by the type commander to assist the ship during overhaul.)
3. Training of personnel during the overhaul.
4. Security—including protection against fire, flooding, theft, and sabotage.

SHIP'S FORCE WORK

All work within the capability of the ship's force should be accomplished by members of the ship's company. The cost of such work, when performed by the shipyard, ordinarily is disproportionate to the value received. A schedule of ship's force work should include names of persons responsible for accomplishment, estimated date of completion, estimated number of man-hours required, and the materials and tools required from the yard. As pointed out later, copies of the ship's force work list must accompany the ship's shipyard repair requests or work lists.

TRAINING

Plans for training during the overhaul period should be based on the objective to be ac-

complished by the end of the period. Local training facilities and fleet schools should be utilized to the maximum degree, consistent with attaining a good overhaul.

LEAVE

Shipyard overhaul periods give time for clearing up backlogs of leave accrued while the ship was in an operational status. The plans should provide for an equitable distribution of leave to personnel while maintaining a force of shipyard work inspectors who have the know-how to ensure satisfactory work. A period of turn-overs should be arranged between the return of one leave party and the departure of another.

SECURITY

While the ship is undergoing overhaul, special precautions must be taken against fire, flooding, theft, and sabotage. The shipyard is prepared to give assistance in matters of security, but the responsibility for establishing security measures remains with the ship.

PREPARING AND SUBMITTING WORK REQUESTS

Work requests must be submitted by the ship to the shipyard in accordance with the specific instructions of the appropriate fleet and type commanders or, for ships not assigned to a type commander, the commander is responsible for supervision of the overhaul funds.

Every department head of a ship has the responsibility according to Navy Regulations of ensuring proper operation of all equipment assigned to the department. The division officers and the division leading petty officers are responsible to the department head for many of the details connected with the proper operation of the equipment within the cognizance of their individual divisions.

In making up work requests it is customary for the weapons officer to require his division officers to submit rough work requests on all inoperative or malfunctioning equipment within their division, electronic or otherwise. As a weapons division petty officer, you would prepare rough work requests for all malfunctioning equipment in your division. The division officer and the weapons officer screen these requests before turning them over to the engineer officer. The engineer officer, who has the responsibility for making up work requests on

nonelectronic equipment in the department, would investigate the requests on nonelectronic items submitted. He usually accepts the electronic items as submitted. The purpose of rough requests on nonelectronic items is to ensure that no equipment is overlooked.

The best rule for you to remember is that you should submit a rough work request for ANYTHING inoperative in your division. You can't afford to quibble over who is responsible.

Work requests should be worded carefully to enable the shipyard to conduct advance planning and estimating. The requests should accurately describe conditions or symptoms that can be used to analyze the fault and decide the general extent of replacement parts and work required. Such generalities as "Requires complete overhaul," "and inspect and repair as necessary" are insufficient for proper analysis. Nameplate data; drawing numbers; and piece numbers or circuit symbols; and status, if known, of special material required for the repairs, should be included. Approved alterations equivalent to repairs "D" type SHIPALTS and those approved by the type commander, except ones designed for accomplishment by forces afloat, are to be included in the shipyard work lists. Unapproved alterations, which sometimes are entered on the work lists under guise of repairs, will be disapproved by the type commander.

If the CSMP and other records have been maintained properly, writing repair requests is a relatively simple matter. The usual procedure is to write the work requests in the rough, using the history card of the unit concerned to obtain nameplate data, plan numbers, and location data, and the repair record card for the description of the repair required and the reason therefor. After all work requests for items of a category (such as hull) are written, a priority number is assigned each item within its category. Requests are then assembled in order of priority for final typing.

JOB ORDERS

Upon reaching agreement at the arrival conference on each item to be undertaken, the shipyard planning department issues job orders authorizing the work to be done by the production shops. Each job order clearly defines the scope of work, includes complete specifications, and identifies the necessary plans. Job orders are not issued for all work at the same time. The

first to be issued are those for jobs requiring practically the entire availability period. Other orders are issued as soon as possible thereafter. If design plans are required for the accomplishment of any specific item, the job order issue date is coordinated with the planned completion date. In any event, job orders for all items approved at the arrival conference are issued by the time the one-third point in the overhaul period is reached.

Check the job orders against the work requests to ensure repairs are adequately covered.

Ship's Superintendent

The ship's superintendent is a naval officer attached to the production department of the naval shipyard. He acts as liaison officer between the ship and the yard. In most yards it is customary to assign one officer as ship's superintendent for each ship. A ship's superintendent can aid the ship a great deal in obtaining a successful overhaul.

Usually he is on hand when the ship arrives. He checks to make certain that required dock services are furnished promptly. He attends the arrival conference and helps coordinate decisions.

The ship's superintendent maintains a close relationship with ship's officers and key enlisted personnel, civilian planners, shop supervisors, supervisors in charge of repair details on board ship, and other naval shipyard supervisory personnel. When delays or interferences develop on a repair job, he can check immediately with responsible yard personnel and obtain information to assist in overcoming difficulties. The ship's superintendent usually can furnish or obtain immediately any information requested by ship's force. He also can keep the ship's key personnel posted on the progress of all jobs. The ship's superintendent is available for advice on (1) repair procedures, (2) unsatisfactory work by yard personnel, and (3) tests made by the shipyard. The primary duty of the ship's superintendent is to assist the ship in all matters regarding repair when the ship is in the yard.

Ship's Progressman

The ship's progressman is a civilian assigned to the production department of the naval shipyard. He has the job of keeping a running check on the progress of all shipyard work. It

is customary to assign one progressman to each ship.

In addition to keeping the production department informed, the ship's progressman keeps the ship posted on the progress of each job. Because of his experience and knowledge of the naval shipyard, the ship's progressman is in a good position to give assistance, advice, and information on any repair problems that may come up.

Checking On Progress Of Shipyard Work

During a shipyard overhaul, the ship submits weekly progress reports in accordance with the type commander's instructions. The best method of keeping track of the numerous repair jobs is by means of a progress chart. Usually, one chart is made out for shipyard work and another for ship's force work. The job order number and title are listed in the left-hand columns. The right-hand columns are marked to show the percentage of completion for each job listed. One copy of the progress chart usually is posted outside the operations office, and ship's personnel keep it up to date. Many ships use the same type of progress chart for tender or repair ship overhaul periods.

In checking on the progress of a job one must have detailed information of the work to be accomplished. This information is obtained from the job orders issued by the planning department.

Some naval shipyards hold a weekly repair progress conference. This conference is attended by ship's representatives as well as all interested shipyard personnel. Customarily, jobs encountering delays or other difficulties are discussed. The ship's superintendent and progressman are important yard personnel who can contribute to these conferences.

Additional Repair Jobs

As a routine step, it is necessary to prepare supplementary repair lists to include items arising subsequent to submission of the original lists. Additional repairs are sometimes required because of recent voyage casualties, or because of conditions discovered during shipyard tests and inspections.

In the period (approximately 3 months) between the submission of the original work lists and the ship's arrival at the shipyard, there

might be some unforeseen difficulties that will require shipyard repairs. These requests are forwarded on the first supplementary work list. The list should be completed before the ship's arrival at the yard.

The shipyard holds numerous tests and inspections in accordance with an established policy and ship's request items. These tests and inspections may bring out some unknown repair items. Usually when these initial tests and inspections are completed, a supplementary repair list is made out to cover any defects that were found. This repair list is called the 1st or 2nd supplement, as applicable.

Besides the instances mentioned, there ordinarily should be no need for submitting supplementary repair items. For the most part, last-minute requests indicate the ship's maintenance program is inadequate, that the CSMP is not up to date, or it is indicative of a lack of experience or knowledge in submitting the original list.

INSPECTION DUTIES OF SHIP'S FORCE

The inspection of work is the responsibility of BOTH the repair activity and the ship. The repair activity should require such inspections as ensure proper execution of work and adherence to prescribed specifications and methods. The ship makes such inspections as may be necessary to determine if the work is satisfactory, both during its progress and when completed.

The responsible Fire Control Technician should schedule his work in such a manner that he is free at all times to inspect and check the progress of work involving his spaces and equipments. A check should be made to see that required tests are made by the shipyard before the job is considered fully completed. The job order lists any tests that must be made by yard personnel.

If unsatisfactory work is performed by shipyard personnel, follow the instructions of your engineer officer. Talking it over in a friendly manner with the workmen usually solves the problem. If it doesn't, notify your division officer or weapons officer, who can take up problems of unsatisfactory work with the ship's superintendent. In exceptional cases the commanding officer of your ship can take action in accordance with Navy Regulations.

On many ships it is customary for your division officer or weapons officer to check with

you before he signs completion of a job order. By continuous inspection of shipyard work and checking off jobs completed satisfactorily, you can furnish the required information without unnecessary delays.

PLAN FOR LEAVING SHIPYARD

Planning relative to the completion of overhaul must be detailed carefully and must cover the final weeks of the overhaul. The planning should provide for the timely accomplishment of the following:

1. Completion of all repairs and alterations.
2. Postrepair tests of machinery and equipment.
3. Basic loading of equipage, repair parts, stores, provisions, and fuel.
4. Return of personnel from school and leave.
5. Training of personnel in preparation for the dock trial, postrepair sea trials and/or postoverhaul operations.
6. Completion of postrepair trial and post-trial repairs and adjustments.
7. Check for deficiencies, utilizing training command arrival inspection checkoff list and type commander administrative inspection checkoff lists.

Readiness for Sea Period

A basic readiness for sea (RFS) period of 7 days is established for all active ships commencing immediately after completion of a regular shipyard overhaul period. The RFS period may be varied by the type commander as necessary for a specific ship. An RFS period is assigned for the specific purpose of allowing the commanding officer time for preparing his ship for sea. Therefore, shipyard work, unless it is of most urgent nature and authorized by the type commander, may not be performed during this period. Plans for the RFS period should provide for the timely accomplishment of:

1. Radar range calibration.
2. Structural test firing of newly installed armament.
3. Operation at sea for machinery tests.
4. Loading of ammunition.
5. Completion of loading of equipage, repair parts, stores, provisions, and fuel.
6. Test of all repaired and newly installed equipment.
7. Other adjustment and calibration of ship's equipment, as required.

FIELD ASSISTANCE

BuWeps and BuShips have technical assistance services available to the fleet. Some of these are listed below.

FIELD ENGINEER ASSISTANCE

Assistance of field engineering services may be obtained when technical difficulties are beyond the repair capabilities of your ship. Certain field activities of the Navy have contract engineers assigned to them, and some engineers are assigned directly to Commander Service Force, Pacific Fleet, or to Commander Service Force, Atlantic Fleet. The engineers are specialists in particular equipments. An emergency request may be telephoned to the nearest activity where the specialist is located, but the written request must follow and confirm it. The request is sent by the commanding officer, but you need to supply the information regarding details of the casualty or of the work required, your best estimate of the time it will take to do the work, and other pertinent information. Remember that these engineers are paid overtime rates for work beyond 8 hours per day and extra payment for work done on Saturday, Sunday, and holidays. You and your men should do as much as possible of the preliminary work of dismantling, etc., in order to reduce the costs. Be ready to assist (and learn in the process) when the special assistants arrive. According to BUWEPSINST 8000.2, field service engineers are available for maintenance support of all fire control systems; enclosure (1) of that instruction lists the location of the engineers, the types of equipment they service, and the place to send the request for their services.

Assistance Teams

After a major overhaul of an installed weapon system or systems, the ship may have to be re-qualified. A Ships Qualification Assistance Team (SQAT) may be assigned to the ship to assist in conducting the trials. The weapon system performance is demonstrated by means of nonfiring tests, and dynamic system tests which include at-sea operations and firings. The assistance team will provide technical and training assistance to the ship's weapons crew, determine if there are any design deficiencies in the system, collect performance data on the system, and help develop operational

procedures. Service engineers from the equipment vendors are part of the team.

The request for an assistance team is made by the CO, and final responsibility for readying and operating the ship's weapons systems and for training and demonstrating the competence of the crew remains with him. The duties of the FT 1 and C include the daily training and drill of the men in the operation and maintenance of the fire control equipment. The assistance team can show you how to locate troubles and ways to correct them. If a team is assigned to your ship, learn all you can while they are aboard. They can be of much help to you.

MOBILE ORDNANCE TECHNICAL UNITS (MOTU'S)

Mobile ordnance technical units (formerly Mobile Ordnance Service Unit (MOSU)) under the direction of the Weapons Service Office provide technical skill and knowledge in support of the operating forces, shore establishments and various Bureaus of the navy with emphasis on new developments. They accomplish emergency repairs to ordnance equipment beyond the capabilities of ship's force and local repair forces at any location. These repairs are limited to those in which the following are available: spare parts, tools, test equipment, publications and drawings. MOTU also organizes and trains emergency OrdAlt teams as required to accomplish OrdAlts or changes to ordnance equipment. They also provide technical advice on repair and upkeep procedures and maintenance standards, diagnose operating difficulties, and inspect and perform tests on ordnance equipment. Services of MOTU may be obtained through type commanders.

SHIP ARMAMENT INVENTORY LIST (SAIL)

The Ship Armament Inventory List (SAIL) is produced on data-processing equipment. It includes only those systems and components indicated in chapter 4 of Index of Alterations to Ordnance Equipment (ORDALT 00). Figure 11-1 is a sample page of SAIL. It replaces the Ordnance Inventory/ORDALT Status Reporting Program formerly used. Each ship has two copies of SAIL. Prior to a scheduled overhaul, one copy should be annotated with OrdAlts that have been completed since the last printing; this copy should be sent to BuWeps 7 months prior

to the scheduled availability. The other copy is kept on board. Revised copies of the SAIL will be sent to each ship before overhaul. After completion of overhaul, annotate the SAIL to indicate all changes, deletions, additions, and corrections and forward a copy to BuWeps. Changes made at other times are reported on Ship Armament Inventory List (SAIL) Change Report, NAVWEPS Form 8000/19. BuWeps again revises the SAIL to include the changes made at overhaul. When you receive the revised SAIL, destroy the previous one.

The SAIL lists in sequence the following: all items pertaining to missile launchers, turrets, mounts, rocket launchers, projectors, torpedo tubes and depth charge release equipment; all items pertaining to fire control equipment, target designation systems (TDS), and weapons direction system (WDS); all items pertaining to missile test and telemetering equipment; and all items pertaining to target control systems. If there is an asterisk in the COMP column (fig. 11-1) after an OrdAlt number, the OrdAlt has been completed. Canceled OrdAlts do not appear on the SAIL. However, the number remains on the ORDALT plate on the equipment and on the history record card. The Mark and Mod on the nameplate should agree with the SAIL. If they do not, correct the SAIL copy by lining out the incorrect entry and writing in the correct one. If the Mark or Mod columns contain the letters "NA" or a dash, no information need be supplied; if they are blank, insert the Mark-Mod information. This also applies to the Serial No. column. The serial number on the SAIL should agree with that on the nameplate of the equipment; correct the SAIL if they are not the same. If the serial number or contract number (on rammers or subassemblies of electric hydraulic drives not identified by Mark Mod numbers) exceeds five spaces, enter only the last five digits and letters.

After overhaul and before the annotated copy of SAIL is sent to BuWeps, you will be expected to verify the information regarding fire control equipment and correct any discrepancies.

OAR PROGRAM

The OrdAlt Accomplishment Requirement (OAR) is a list issued by BuWeps, as NAVWEPS Form 8000/16, figure 11-2, about 6 months prior to overhaul of a ship. It shows the OrdAlts in the order of priority of accomplishment,

SAIL SHIP ARMAMENT INVENTORY LIST										
VESSEL NAME				TYPE		HULL #		REVISION DATE		
YAZOO				AN		0092		62 10 09		
TYPE COMMANDER				REASON FOR THIS REVISION						
MINLANT				FOR USE DURING OVERHAUL						
OVERHAUL OR BLDG YARD				DATES						
				YR		MO		DA		
				YR		MO		DA		
NOMENCLATURE				MK	MOD	SERIAL NO	ORDALT NO	COMP	KEY	
20 MM TWIN MOUNT				24	5A	-				
							02294	280	0110	
							02417		0110	
							03008		0110	
							03195		0110	
							03248		0110	
20 MM TWIN MOUNT				24	5B	-				
							02294	280	0120	
							02417		0120	
							03008		0120	
							03195		0120	
							03248		0120	
20 MM TWIN MOUNT				24	5C	-				
							02294	280	0130	
							02417		0130	
							03008		0130	
							03195		0130	
							03248		0130	
TOTALS				3			15	12	3	18

NAVWEPS FORM 8000/15 (6-62)

A

PAGE 1

Figure 11-1.—SAIL, Ship Armament Inventory List, NavWeeps Form 800°/15.

O A R										ORDALT ACCOMPLISHMENT REQUIREMENT									
OVERHAUL OR BUILDING YARD				OVERHAUL OR COMPLETION DATE				TYPE COMMANDER				VESSEL NAME OR ACTIVITY				TYPE		HULL #	
Mare Island				12-1-68				DESLANT				MOON				XYZ		6	
S Y S T E M						E Q U I P M E N T						ESTIMATED				EXPENDED			
ITEM	ORDALT	SHIPALT	NOMENCLATURE			MARK	MOD	SERIAL	NOMENCLATURE			MARK	MOD	SERIAL	CONTRACT SERVICE ENGINEER MAN HOURS	INDUSTRIAL ACTIVITY MAN HOURS	INDUSTRIAL ACTIVITY MAN HOURS		
1	4006		5/54 DP SGL MT			42	7	55											
2	4069		5/54 DP SGL MT			42	7	55	SHLD			61	1	86		185			
3	4188		GFCS			68	2	51	RDR Set AN/SPG 53			53	-	12		112			
4	3216	REQD	GUN DIR			37	20	51								79			
																830			

APPROPRIATION	APPROVED FUNDS	ORIGINALLY PREPARED	REVISED DATE	PAGE	TOTALS	MAN HOURS	DOLLARS
1788888.2415	7670	10/62		1		1206	7670

Figure 11-2.—OrdAlt Accomplishment Requirement (OAR) NavWeps Form 8000/16.

63.13

the estimated man-hours required to accomplish it, and estimated cost of each. The ship receives one copy, which must be given a thorough review and a report submitted within two weeks. The report must list all the OrdAlts completed after the "Prior to Overhaul" SAIL was submitted, OrdAlts that should be on the OAR list, OrdAlts that are on the OAR list but are not applicable, and a list of all the OrdAlt material on board. The report goes to BuWeps, BuShips, and the Ordnance Supply Office (OSO), and they can amend the OAR list, requisition supplies, and plan to accomplish as much of the additional work as is possible within the limits of the funds appropriated and the time available.

OAR Lists are also published by BuWeps for new ships and major conversion ships. The

lists are reviewed by the ship and the shipyard, and revisions submitted as in the case of ships in the active fleet.

Within 10 days after completion of overhaul, the fitting-out yard submits a report of what has been accomplished. A revised SAIL, including information from the latest OAR, is then issued by BuWeps and sent to the ship.

IMP

The Integrated Maintenance Plan (IMP) was devised by BuWeps to provide adequate maintenance methods for complete weapons systems and at the same time simplify reporting methods

without loss of data needed for adequate knowledge of what is being accomplished and of areas that need improvement.

Since IMP includes testing and operation of the whole weapon system, planning of the weekly and the daily schedules must be done in cooperation with the POs responsible for parts of the system other than the fire control system. The shipboard maintenance plan is prepared at higher echelons, but you and other POs need to work out a schedule for each day. Figure 11-3 plots the operation of IMP in shipboard maintenance. Note the three areas—planning, performance, and feedback.

The Integrated Maintenance Plan (IMP) at the present time is in operation on many ships of the fleet. At the present time, IMP is in the process of being incorporated into the Planned Maintenance Systems (PMS) which is in turn a part of the Standard Navy Maintenance Management System.

The Daily System Operability Tests, (DSOT), is the heart of the IMP program. From DSOT, IMP proceeds to other integrated system tests which lead into an associated system troubleshooting logic tree. Equipment troubleshooting pyramids and signal flow diagrams are being developed for fire control equipment. Maintenance procedures are being prepared on Maintenance Requirement Cards. As fast as these are prepared by BuWeps, they will be sent to the operating units. An integrated maintenance schedule and a log book will replace and supersede current individual schedules and logs.

STANDARD NAVY MAINTENANCE MANAGEMENT SYSTEM

The Standard Navy Maintenance Management System (SNMMS) is a ship-wide program made up of the Planned Maintenance System (PMS) and the Maintenance Data Collection System. The Integrated Maintenance Plan (IMP) is a subdivision of the Planned Maintenance System (PMS). SNMMS is a plan of action to improve the management of maintenance and material resources in support of the Operating Forces of the Navy. Modern weapon systems, with their components in various parts of the ship and requiring close cooperation to function as a system, must be operated, tested, and maintained as a system. A uniform plan of maintenance with central management will simplify and reduce the number of the reports, and will

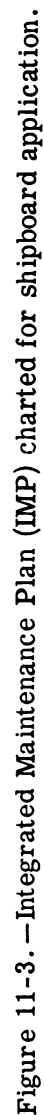
tend to upgrade maintenance to the standard set by CNO. A uniform reporting system will also make it possible to make effective use of data processing equipment to coordinate the report results.

To install this system in all Bureaus of the Navy is an extensive undertaking. It requires the cooperation of all personnel and can benefit all of them. It is not something new and hard to accept, but extends planned maintenance to include all parts of a weapons system and introduces the use of mechanical means of data recording, correlating, and analyzing. In addition, it includes the supply system.

The Satterwhite System is a predecessor of the Planned Maintenance System (which includes IMP). The Job Description Cards of the Satterwhite System correspond to the Maintenance Requirement Cards which will be used in the SNMMS. The Master Plan corresponds to the Long Range Schedule, and the Weekly Work Plan to the Weekly Schedule. You have used the Job Description Cards of the Satterwhite and the PRISM systems, and know how helpful they are. You may not have helped to prepare the Weekly Work Plan but you have worked according to the plan; calling it a Weekly Schedule is not going to make your work startlingly different. CNO's Planned System Maintenance covers the work of BuWeps, BuShips, and BuSandA in relation to a weapons system, and will operate to correct deficiencies in design and quality, and lack of spares, as well as to improve maintenance and reduce costs.

PROGRAM MILESTONE PLANS

Program Milestone Plan A is the plan for the development of the maintenance system (preparation and distribution of the maintenance cards for all components on a ship), and installation on ships and shore activities. Program Milestone Plan B is the plan for a uniform data collection system. This must go hand in hand with the maintenance plan. The record keeping aboard ship, and reports to be made, are included in this part of the plan. Redundant and unnecessary reports are to be eliminated and the reporting is to be simplified for machine processing. Teams will be sent to give training in making the reports. As the system is developed, ships will be equipped with the necessary key punch machines; men who have been



trained can transfer the ship's maintenance information to the punch cards. Tender and repair ships will have data processing equipment to correlate the data from the ships' cards sent to them. The compiled data will be sent to CNO and other designated bureaus, offices, and commands.

PLANNED MAINTENANCE SYSTEM MANUAL

The complete maintenance plan for the ship will be contained in the Planned Maintenance System Manual. A copy of the Ordnance Section will be kept in the weapons office for planning and scheduling weapon system maintenance requirements. It is to be used by the weapons officer and the maintenance group supervisors (petty officers). The maintenance groups in the weapons department of a destroyer are gunnery, torpedo, fire control, and sonar.

A plan as comprehensive as this requires some time to implement and the planned program for this extends over several years. Test runs will show up flaws and weak points, and revisions will be made to correct them. Changes will be made as needed when the system is in use. You may be part of a group to make a trial run of the system.

SCHEDULING MAINTENANCE

Each ship will have a long range schedule which includes all the maintenance work to be done between overhauls. It is displayed on a schedule display board, and consists of the Cycle Schedule and two quarterly schedule forms (the current quarter and the succeeding quarter). Maintenance requirements are scheduled by weeks and are determined from the Cycle Schedule. There are spaces for each maintenance group (gunnery, etc.). The quarterly schedule is prepared by the department head, the division officers, and the maintenance group supervisors. The latter prepare the weekly schedule from it, in which they assign specific jobs to personnel by name. The weekly schedule is posted in the work area of the maintenance group. Figure 11-4 shows a sample weekly work schedule. The form is made of plastic and is written on with a #2 lead pencil. It is cleaned with a soft rubber eraser and is used over and over. The page numbers in the third column (fig. 11-4) refer to the pages in the Planned Maintenance System Manual. The numbers in the daily columns

are the maintenance requirement numbers that appear at the top of the maintenance requirement cards (fig. 11-5). The man who is assigned to do the work pulls the MRCs from the set as he needs them to perform each job. As each job is finished, he places an X on the weekly schedule after the number of the completed job. Any work that is not completed at the end of the week is circled and is rescheduled for the next week or another time. The petty officer who is the maintenance group supervisor reschedules all the circled items. He also fills in the column on "Outstanding repairs," in which he explains why some work was not or could not be completed. Possible reasons are lack of qualified men, shortage of repair parts, etc. At the end of each week he also updates the quarterly schedule by marking on it the jobs that were completed during the week, and circling those that were not completed. At the end of the quarter, the quarterly schedule is filed in the maintenance records.

The PO also supervises, assists, and teaches the men as they do the maintenance work; and he checks the completed work. Do not "gun deck" the records, and do not give your O.K. to unacceptable work.

MAINTENANCE REQUIREMENT CARDS

Standard forms for stating the maintenance requirements have been prepared. These forms are being distributed to all the operating forces as soon as possible. Figure 11-5 shows a sample card. Each ship will have a complete set for all the equipment on board.

The master set of maintenance requirement cards is kept in the weapons office. Corrections or changes are added as necessary. Discrepancies may be due to peculiarities of the ship's installation, and these may be discovered when maintenance is attempted. The men report the difficulty to the supervising petty officer; he checks it out, and makes a corrective entry on the maintenance requirement card.

The Group Maintenance Book is similar to the Planned System Maintenance Manual except that it contains only the parts applicable to the work of the group. It is kept in the working space of the group, along with the maintenance requirement cards that apply to the work.

The maintenance requirement cards may also be used as a training aid in teaching the men how to do the work. Although the MRCs contain step-by-step instructions for each job,

GUNNERY									
WORK SCHEDULE FOR WEEK OF _____									
COMPONENT	MAINTENANCE RESPONSIBILITY	PAGE	MON	TUE	WED	THUR	FRI	SAT/SUN	OUTSTANDING REPAIRS
(1)	(2)	(3)	- - -	- - -	-(4)-	- - -	- - -	- - -	
MOUNT 51		GM-1 1-4	W1-7 D1-D2	D1-D2	M-1 D1-D2	D1-D2	D1-D2	D1-D2	
MOUNT 52		GM-1 1-4	Q1, Q2 W1-7 D1-D2	D1-D2	Q3 D1-D2	D1-D2	M-1 D1-D2	D1-D2	
MOUNT 53		GM-1 1-4	Q1, Q2 W1-7 D1-D2	M-1 D1-D2	D1-D2	Q3 D1-D2	D1-D2	D1-D2	

SAMPLE WEEKLY WORK SCHEDULE

FORMAT INCLUDES ALL DAILY AND WEEKLY CHECKS PREPRINTED

WHERE USED: POSTED IN MAINTENANCE GROUP WORK SPACE IN ALUMINUM HOLDER.

WHO USES: MAINTENANCE GROUP SUPERVISORS AND MAINTENANCE PERSONNEL.

92.99

Figure 11-4.—Sample of weekly work schedule.

practice under close supervision will speed the operation and remove many uncertainties about the method of doing the work. An alert PO can give many pointers that will make the work easier, faster, and more accurate. Do not assume that a written set of instructions will enable any man to do any required maintenance work. Some of your men will have a natural mechanical bent and will be able to "pick up" the work easily, but others will require careful, detailed teaching. You will soon discover who they are, and can tailor your instructions to fit the needs of the men.

WEAPONS DEPARTMENT REPORTS

"Consolidated List of Recurring Reports Required by the Bureaus and Offices, Navy Department, from the Operating Forces of the Navy," OPNAV INSTRUCTION 5213.7, is indeed a formidable list of reports. A large number of the reports are made by the officers; however, the petty officers of the different divisions of the ship must supply much of the information necessary for those reports. Rough logs are kept by the lower rated men. Routine cleaning

is not entered on logs, but routine maintenance that is not included on the maintenance checkoff list is entered on the rough log. Hours of operation, and drills and exercises are rough entries that are used in preparing smooth logs. You will check the rough logs prepared by your men and prepare a weekly log from the daily entries, or combine the unit logs into a system log. The smooth log may be prepared by the division officer or you may be required to prepare it. Entries on the history cards are made from the smooth log.

When not typewritten, entries should be hand-printed, preferably in ink. A ballpoint pen will produce legible carbon copies, which often are required.

It is better to write "NA" (not applicable) in a space on a report form than to leave it blank. It shows that you did not overlook the question. Be sure that mark, mod, serial, and part numbers are listed for the equipment tested, repaired, overhauled, or altered. Quite often OrdAlts are applicable only to certain units, identified by their serial numbers. This is because the units manufactured after the alteration was ordered or authorized have had the change incorporated at the factory.

P.M. <u>FT-3, CC-4</u>	EQUIPMENT/ SYSTEM <u>COMPUTER MK1A</u>
RELATED P.M. _____	
LOCATION <u>Plotting Room</u>	
REFERENCES <u>OP1064A (1st Rev), OD 3000, CD 4236</u>	
OPERATION AND PURPOSE:	
Lubricate the Starshell Computer and Selector Drive MK1 to prevent excessive wear.	
RATE REQ <u>FT3, FTSN</u>	MAN MINS <u>180</u> TOTAL TIME <u>90</u>
TOOLS/SPARES/MATERIALS:	
Vacuum cleaner	9/16" wrench
Lint free cloth	1/2" wrench
Grease, type MTL-G-15793 (BUORD)	
Oil, type MIL-L-6085	
Soft copper wire	
4 small bristle brushes	
Flashlight or computer light	
SAFETY PRECAUTIONS, DETAILED METHOD AND RECORDS REQUIRED:	
1. To lubricate the Starshell Computer:	
(a) Remove front and rear covers.	
CAUTION: After removing nuts and washers, run vacuum cleaner around cover to pick up chips, dust, etc.	
(b) Using brush and cloth, remove grease from exposed gears and apply new coat of grease.	
(c) Using soft copper wire and oil, apply 2 drops of oil to all bearings.	
NOTE: Do not overlubricate. This oil is primarily for prevention of corrosion.	
(d) On the Multipliers, using lint free cloth, remove old grease and oil. Apply a thin coat of oil to guide rails, rollers and pivots. Apply grease to slides, slots and grooves.	
(e) Apply thin coat of grease to all limit stops.	
2. To lubricate the Selector Drive:	
(a) Remove upper cover.	
NOTE: Be sure cover and surrounding area is clear of dust, dirt, etc.	
(b) Clean old grease out of selector drive. Inspect gears for excessive wear and proper synchronization.	
(c) Apply new grease and replace cover.	

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Figure 11-5.—Maintenance Requirements Card (MRC), OpNav Form 4700-1 (6-63), with magazine sprinkler test information.

Component Failure Reports

Failures and malfunctions of nonexpendable units of shipboard ordnance systems are reported on NAVWEPS Form 8000/13 (fig. 11-6). Equipments for weapons control, weapons direction, missile telemetering, missile checkout, and associated test and support equipment, as well as the launcher, are reported on the form. It is NOT used for reporting expendable material—missiles, depth charges, etc. Also, it is not used to report missile test results; it is used to report failures of missile test equipment. Test RESULTS are reported on form 8800/2. Do not confuse these two reports. Detailed instructions for completing NAVWEPS Form 8000/13 are contained in Enclosure (1) of BUWEPSINST 8000.3.

You may want to reproduce the instructions to use when you teach your men how to fill out the report, or you may use it as a guide for yourself in giving instructions. On the reverse side of the form is a long list, alphabetical, of various defects. Use the code numbers in reporting the type of defect (item 38 on the form). If the particular defect you are reporting is not among those listed, use the defect code no. 099, Other, and explain under Remarks.

Failure of electronic equipment in the SAM system that is under BuShips cognizance is reported on NAVSHIPS Form 4855 in accordance with BuShips Instruction 10550.73. This is the revised form, which replaces Form DD 787. Operational time logs for the electronic equipment are also reported on that form. BUWEPSINST 8821.4, enclosure (1) lists all the equipments that are to be reported on NAVWEPS Form 8821/5 and not on NAVSHIPS 4855.

Operability and Reliability Reports

The Daily System Operability Tests (DSOT) provide systematic, unambiguous, quickly performed test procedures for determining the readiness of the weapons system. The results of the tests are recorded on NAVWEPS Form 8821/5 (fig. 11-7), Equipment Status Report, which is submitted weekly to the addresses listed in the latest change to BUWEPSINST 8821.3. Code letters are used to indicate the condition of the weapons system, with space for recording each hour of the day. The code letters are explained in enclosure (1) of BUWEPSINST 8821.3. Whenever the system is down for any reason, the explanation should be given

under "Remarks". In the example shown in figure 11-7, the system could not be operated because of failure of support equipment (code P); the name of the failed equipment and the type of failure are written into the Remarks column. Each ship is notified on which equipments it is to report and a Form 8821/5 is submitted each week for each such equipment.

Commanding Officer's Narrative Report

This report is submitted quarterly. The CO reports on the entire weapon system, including missiles, missile handling and checkout equipment, fire control radar, computer, weapon direction equipment, launching system, stable element, search radar, switchboards, etc. He gives his overall appraisal of the weapon system, of the supplies (spares, etc.), system documentation (publications), quality and training of personnel, technical assistance requested and received, and his recommendations for improvement or areas to be investigated.

EQUIPMENT LOGS

It is important that records relating to fire control equipment be maintained in accurate, systematic fashion. These records are mainly in the form of preprinted cards which are maintained in a material history binder. The equipment log is kept with the equipment of which it is the record and is sent along with the equipment when the equipment is transferred either to another activity or into storage.

Equipment Rough Logs

The rough log for each equipment may be a notebook record of all work, tests, alterations, repairs, etc., entered as soon as performed. Each man enters the work he performs on the equipment, not later than the same day, so vital details will not be left out. Include as minimum information the symptoms of any trouble along with the step-by-step breakdown of the troubleshooting techniques used and the results of the troubleshooting effort. Include the voltages read at specified test points, the types of meters used, and their sensitivity. Include oscilloscope records, hand drawn if necessary.

Locally prepared forms may be used on which checkmarks will replace a story description. Such sheets save considerable time in writing up the rough log.

Figure 11-6. --Weapon Systems Component Failure Report, NavWeps Form 8000/13 (9-62).

FIRE CONTROL TECHNICIAN 1 & C

BUREAU OF NAVAL WEAPONS

EQUIPMENT STATUS REPORT
NAVWEPS FORM 8821/5 (3-62)

REPORT SYMBOL BUWEPS 8821-5

SHIP	CLG-12				EQUIPMENT										WEEK BEGINNING										
					AN/SPG-49 S/N 11										1 July, 1962										
DAYS	HOURS																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SUNDAY	D	D	D	D	D	D	D	D	C	D	D	D	D	D	H	H	H	H	D	D	D	D	D	D	D
MONDAY	D	D	D	D	D	D	A	A	C	A	K	K	A	A	A	A	A	D	D	D	D	D	D	D	D
TUESDAY	D	D	D	D	D	D	A	A	C	K	A	A	A	K	K	K	K	D	D	D	D	D	D	D	D
WEDNESDAY	D	D	D	D	D	D	A	C	A	A	A	A	L	L	L	L	B	B	B	B	B	B	K	K	K
THURSDAY	K	K	K	K	K	K	A	A	C	A	A	A	A	A	A	A	A	D	D	D	D	D	D	D	D
FRIDAY	D	D	D	D	D	D	K	K	K	A	A	A	A	A	A	A	A	D	D	D	D	D	D	D	D
SATURDAY	D	D	D	D	D	D	D	D	C	D	D	D	D	P	P	P	D	D	D	D	D	D	D	D	D

CATEGORY, DATE/TIME, REMARKS

When equipment is reported in Category M, list short spares; in Category P, list support equipment causing down status; and in Category C, describe nature of help needed (shipyard crane, technical representative, etc). Other information should include category and date/time.

Category	Date/Time	Remarks
P	7 July, 1310	Failure of Waveguide pressurization

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Figure 11-7. —Equipment Status Report, NavWeeps 8821/5.

Equipment Smooth Log

Much of the information on the rough unit logs will be entered by lower rated men. You as an FT 1 or C will transcribe the entries to the battery log. Data must be complete, legible,

and permanent. Smooth log and Ordnance History Cards are prepared by the battery officer from the battery rough logs. The smooth log is kept with the equipment. If it is kept on reproducible vellum, copies can be made for BuWeeps or other activities requesting or requiring

them. History cards may be used instead of smooth logs and data transferred to the cards at intervals.

ORDNANCE SUPPLY

The supply of ordnance material is coordinated through the Ordnance Supply Office, Mechanicsburg, Pa. This office is operated jointly by the Bureau of Naval Weapons and the Bureau of Supplies and Accounts. The Ordnance Supply Office (OSO) is the inventory control point for ordnance materials. It is responsible for control inventories, procurement, and distribution. OSO also maintains records, catalogs, logs (NavOrd lists), and stock levels, and regulates the flow of material throughout the Navy distribution system but does not itself maintain stocks of repair parts and equipments.

COSAL AND WHAT IT MEANS

The Coordinated Shipboard Allowance List (COSAL) was explained and illustrated in your Military Requirements for Petty Officer 3 & 2, NavPers 10056-A, text, cited above. As an FT in the Weapons Department the parts of the COSAL that concern your work are the sections that list the fire control systems and the tools and repair parts allowed for their maintenance. The type and quantity of repair parts allotted a ship was determined by studies of requirements in the past. Each ship has a COSAL prepared just for it, and the ship is stocked accordingly.

The ordnance section of the COSAL is made up of an introduction and three separate parts. The introduction is prepared by the Ordnance Supply Office (OSO) and gives complete information on the use of the COSAL. Study this introduction carefully before using the COSAL.

The stock numbers given in COSAL listings are Federal Stock Numbers (FSNs). The Federal Supply Classification system and the numbering system were explained in Military Requirements for Petty Officer 3 & 2, NavPers 10056-A; review it if you have forgotten.

ORDNANCE SEGMENT OF COSAL

The ordnance segment of the COSAL is an allowance list of ordnance equipments, equipage, and supporting repair parts and other materials, tailored to the individual ship. As each active

ship with ordnance installations undergoes overhaul, it is supplied with a new ordnance segment of the COSAL. All active fleet, new construction, and major conversion ships with installed armament receive an ordnance segment of the COSAL. Only the items listed will be placed on board, in the quantity listed.

RECORDS AND REPORTS FOR COSAL

The COSAL for each ship is prepared by OSO, which also stocks the ship with the listed equipments and repair parts, either at outfitting of a new or a converted ship, or just before overhaul. Minor revisions to the COSAL are made as pen-and-ink changes on the ship's copy. More extensive revisions or additions are distributed as changes.

The COSAL does not generate any additional reports or records but simplifies your record keeping. It gives you the Federal Stock Number for most of the items you have to order, and saves much looking up of those numbers. It lists the items your ship is allotted, so you will not order something you may not have.

HOW TO ORDER SUPPLIES ACCORDING TO COSAL

Part I of the COSAL lists your equipment and its major components, and gives the component identification numbers (application code). The identification number acts as a page number for a more complete breakdown of the components in Part II.

Part II is the Allowance Parts List of repair parts needed to support the items in Part I. If a quantity appears in the allowance table of Part II it is considered to be an on-board item. The Federal Stock Number for each item is given in Part II.

Part III of the COSAL when fully consolidated will be the final authorized on-board allowance quantity of a repair part. This part of the COSAL is of more use to the storekeeper than to you. It is here that the total allowance of parts which may be common not only to the ordnance section of the COSAL but other departments as well, are added together. That is, your section of the COSAL may permit you an allowance of three particular limit switches. The engineers' COSAL may show their allowance to be six of the same switches. Part III of the COSAL will show a total of nine of these switches, giving their applications.

PROCUREMENT OF MATERIAL

Procurement is the act of getting or obtaining something. As a rule, your supply officer will procure the material for you, provided you furnish him with the necessary information. The COSAL tells you what material is authorized. You must know what forms to use and the procedure for initiating procurement action.

Material may be procured by: (1) requisition, (2) purchase, (3) transfer, and (4) manufacture.

The requisition method is the one you will use most often. Use Requisition Form DD 1150 (fig. 11-8) to obtain your supplies and repair parts from the ship's storeroom. A supply of the forms is usually kept in the weapons office. While you are in the weapons office, check the COSAL to find out if the part you wanted is stocked, and copy the Federal Stock Number on the form. If it is customary on your ship to list the price, look it up and enter it on the form.

When you have filled in the information on Form DD 1150, take it to your department head for his signature, then to the storekeeper. The storekeeper will double-check your information, and if the item requested is in stock, he will issue it to you. He retains the Form DD 1150 as authorization for the supply department to requisition the same item from supply ashore to bring the ship's stock up to allowance again.

It is good practice to maintain a file in the weapons office of all material requisitioned from supply containing a record of the request or requisition numbers. These numbers are assigned by the supply department and entered in the upper right-hand corner of Form DD 1150 (Block # 8 fig. 11-8). This number is especially helpful when tracing a part that was requisitioned from an activity other than your ship, such as a shore activity. The requisition number is necessary to start a tracer through the supply system to locate your material if it is unnecessarily long in coming.

If you are unable to determine the Federal Stock Number of a repair part that you need, use S. and A. Form 302 (fig. 11-9) to requisition it, and give all the descriptive information that you can. This information will include nomenclature, identification taken from the nameplate, drawings, or any source that will help identify the item.

When you have used a repair part that was stocked in your department, do not put off ordering a replacement for the part.

IN-EXCESS REQUISITIONS

Sometimes it is necessary to request material above the quantity shown for the item on the COSAL. This may be due to excessive breakage of a particular item, or similar reason. Your department must give reasons sufficient to justify the need in excess of the allowance and the supply department prepares the in-excess requisition.

In-excess requisitions are required for all of the following materials:

1. Equipage not on the ship's COSAL.
2. Equipage on the COSAL, but requested in greater quantities than allowed.
3. Nonstandard consumable supplies.
4. Repair parts not listed with quantities on the ship's allowance, for which a requirement can be justified.

Approval of an in-excess requisition does not constitute a change of or addition to the COSAL. If replacement of the in-excess articles is required, additional approval is required.

ISSUING PROCEDURES

Procedures for issuing supplies vary on different ships. Approval by the man maintaining the Departmental Budget Record may be required on some ships. Clearance with the supply department may be required before proceeding to the stockroom with the approved requisition form. Be sure that each man drawing material is instructed to check that each item is received in correct quantity and the price is listed correctly for the material actually received.

SAIL MASTER LIST OF NONEXPENDABLE ORDNANCE EQUIPMENT

The Ship Armament Inventory List (SAIL) was described previously, and a sample page was shown. The method of updating the SAIL for submission to BuWeps was also described. Since the SAIL lists nonexpendable ordnance and the OrdAlts completed on each, no repair parts need be ordered in connection with reporting changes to the list. The repair parts are required for performing the OrdAlts.

VOUCHER (REQUISITION) NUMBER
ASSIGNED BY SUPPLY DEPARTMENT
IF REQUISITION MUST BE
SUBMITTED TO STOCK POINT
IN ORDER TO PROCURE MATERIAL

CONTROL NUMBER ASSIGNED
BY REQUESTING DEPARTMENT

REQUEST FOR ISSUE OR TURN-IN				ISSUE TURN-IN	SHEET NO. 1	NO. OF SHEETS	5. REQUEST NUMBER G 10 47	
1. FROM: WEAPONS OFFICER				6. DATE MATERIAL REQUIRED 4-21		7. PRIORITY		
2. TO: SUPPLY OFFICER				8. VOUCHER NUMBER		9. DATE BY POSTED DATE BY		
3. APPROPRIATION SYMBOL AND SUBHEAD		OBJECT CLASS	EXPENDITURE ACCOUNT (From)	ACCOUNT (To)	CHARGEABLE ACTIVITY	BUREAU CONTROL ACTIVITY NUMBER	BUREAU CONTROL NUMBER	AMOUNT
JOB ORDER								
4. END ITEM IDENTIFICATION		5. NAME AND MANUFACTURER		b. MODEL		c. SERIAL NUMBER		d. PUBLICATION
ITEM NO. (a)	STOCK NUMBER AND DESCRIPTION OF MATERIEL AND/OR SERVICES (b)				CODE (c)	UNIT OF ISSUE (d)	QUANTITY (e)	SUPPLY ACTION (f)
1	1A-1015-177-0119 ARM				ea	2	16.00	32.00
IT IS NORMAL PROCEDURE TO LIST ONLY ONE LINE ITEM PER DD1150 FILLED IN BY STOREKEEPER AT TIME OF ISSUE OF THE MATERIAL								
*ISSUE-I-Initial; R-Replacement TURN-IN-U-Unserviceable; S-Serviceable								
10. ISSUE OR TURN-IN OF QUANTITIES IN "QUANTITY" COL- UMN IS REQUESTED		DATE 4-21		BY W. K. S. [Signature]		11. RECEIVED QUANTITIES IN "SUPPLY ACTION" COLUMN		DATE BY
DD FORM 1150 (9 pt.) REPLACES EDITION 1 OCT 57 1								

SIGNED BY DEPARTMENT HEAD
OR HIS AUTHORIZED
REPRESENTATIVE

MAN ACTUALLY RECEIVING
MATERIAL SIGNS HERE

Figure 11-8.—DD Form 1150 (Request for Issue or Turn-In.)

1. 12

PUBLICATIONS

SOURCES OF ORDNANCE IDENTIFICATION

The publications most often used to identify ordnance material are:

1. Navy Stock List of the Ordnance Supply Office (NSL of OSO). The first three volumes are the ones you will use most for identifying repair parts for requisitioning.

2. Illustrated Parts Breakdown of Ordnance Equipment (IPB). This publication is prepared by OSO. Each IPB is published for one particular type of piece of equipment, and describes and illustrates the relationship of all assemblies and parts comprising the equipment. IPB 0000 is an index of all IPBs.

3. Coordinated Shipboard Allowance List (COSAL), which were previously discussed.

FIRE CONTROL TECHNICIAN 1 & C

REQUEST FOR SPARE PARTS						
NAVSANDA FORM 302						
NAME OF ACTIVITY OR SHIP USS TOPEKA (CLG-8)				REQUEST NO. W-30		
DEPARTMENT WEAPONS				DATE 5/13/64		
SPARE PART BOX NO.				ALLOWANCE LIST: GROUP No.		
STOREROOM No.				PAGE No.		

ITEM NO.	SERIAL NO. OR PART NO.	DESCRIPTION	UNIT	QUANTITY	SPARE PART LIST NO.	ALLOWANCE LIST LINE NO.
1	209746-6	GEAR	ea	1		

ABOVE ITEMS TO BE USED ON/WITH

COMPUTER MK 1A MOD 13

NAME PLATE DATA	SERIAL No.	TYPE No.	MODEL No.	STYLE
	897			
	MFR.'S DRAWING No.	NAVY DRAWING No.	P. C. No.	CONTRACT No.
		209746-6	209746-6	
	HP.	R. P. M.	GPM	CFM
	VOLTAGE	A. C. OR D. C.	AMPS.	OHMS
	PHASE	CYCLE	BORE	STROKE
	SIZE	JOB ORDER No.	CATALOG No.	SPECIFICATION No.

OP 1064A, OP 1064B

ADDITIONAL NAME PLATE DATA

OTHER IDENTIFYING INFORMATION

REFERENCE OP 1064A, OP 1064B

MANUFACTURER FORD INSTRUMENT COMPANY	LATEST ACCEPTABLE DELIVERY DATE 8/13/64
MANUFACTURER'S ADDRESS LONG ISLAND CITY, NY. NY.	
SOURCE OF SUPPLY	

DRAWN OUT OF SPARE PARTS BOX BY	UPON RECEIPT NOTIFY
	J.J. JONES FT1
SUBMITTED BY	APPROVED BY HEAD OF DEPARTMENT
J.B. SMITH FTC	J.H. JOHNSON, Lt. USN

DATE ORDERED 5/16/64	ORDERED FROM NSC, NORFOLK, VA.	REQUISITION No. 50935-2-004369
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☆ U. S. GOVERNMENT PRINTING OFFICE : 1944 16-42008-1

Figure 11-9.—S. and A. Form (Request for Repair Parts.)

One of the most important sources of identification is the information on nameplates. This may include the manufacturer's name, make or model number, size, voltage, and like information. Identification publications such as manufacturers' technical manuals may help you in identifying an item.

ORDNANCE IDENTIFICATION DATA

Ordnance identification data are important in identifying ordnance items. They should be used on all requests for material if the stock number is not available. These data include:

The **MARK NUMBER**, which identifies the particular model of a certain type of ordnance equipment.

A **MODIFICATION NUMBER (Mod)**, which indicates a modification of the basic mark number. Modifications are numbered serially, beginning with zero, for each separate mark.

An **IDENTIFYING NUMBER**, which is the number assigned to the blueprint plan of an ordnance component or assembly. It may be a drawing number, a list of drawing numbers (LD), a sketch number, or an assembly number.

A **PIECE NUMBER**, which is a subdivision of the drawing number and identifies by a serial designation every item appearing on a given drawing. Sometimes the drawing and piece numbers are stamped or etched onto the part itself. Piece numbers are rarely used in later type ordnance assembly drawings. It is now standard practice that each item in a drawing will have its own separate drawing number.

A revision letter is often added to identify a particular revision of a drawing or list of drawings used in the manufacture of a part.

Specific and detailed information on Navy supply is contained in the Bureau of Supplies and Accounts Manual (BuSanda Manual). This manual is made up of several looseleaf bound volumes and is intended more as a reference for the expert than as an introduction for the novice. If you have any question on supply, the answer can probably be found by consulting someone in the supply department who will know the answer or where it can be found.

The BuSanda Manual is kept in the supply department, as are the Navy Stock Lists, the DOD Section of the Federal Supply Catalog, and the Fleet Oriented Consolidated Stock List (FOCSL) which is replacing most Navy Stock Catalogs for shipboard use.

ORDERING PUBLICATIONS

Cognizance symbol "I" designates printed material such as standardized forms, handbooks, instructions, and training publications. They are listed in NAVSANDA Publication 2002, "Navy Stock List of Forms and Publications, Cognizance Symbol I." The initial commissioning allowance is sent without requisitioning. Other recommended publications, classified as Category II, may be requisitioned from Forms & Publications Stock Point, U. S. Naval Supply Center, Norfolk, Virginia, or Oakland, California.

Except where indicated otherwise, order OPs and changes from the Naval Supply Depot, 5801 Tabor Avenue, Philadelphia, Pa.

Whoever is appointed the publications custodian has the responsibility for ordering publications that are needed and keeping changes inserted. He also is responsible for the security of the publications.

HOW TO PREPARE REQUISITIONS

The uses of DD Form 1150 and S. and A. Form 302 were discussed earlier, and you have studied them in Military Requirements for Petty Officer 3 & 2, NavPers 10056-A. The S. and A. Form #302 is used by the Supply Department in preparing its requisitions to the Naval Supply Depot. The use of data processing equipment has brought into use the machine forms called NAVSTRIP and MILSTRIP, which are prepared by the supply department for ordering supplies for the ship.

PRIORITY SYSTEM

The uniform material issue priority system (fig. 11-10) of the NAVSTRIP procedure is important to you. The priorities range from 01 (highest), to 20 (lowest). The time allowed the supply activity for shipping the requested material is adjusted to the priority assigned by the requisitioner as to urgency of need and the force/activity designator assigned by the Navy or CNO to identify it and categorize it on the basis of the military importance of its mission. When you are requisitioning material from the supply department on the ship, you merely tell the supply officer when you need the material, and if you need it soon, why. The supply officer will then assign tentative priority codes. Both the department head and the supply officer must be

UNIFORM ISSUE PRIORITY SYSTEM

Force Activity/Urgency of Need

URGENCY OF NEED DESIGNATORS

FORCE ACTIVITY	TYPE OF FORCE	URGENCY OF NEED DESIGNATORS			
		A UNABLE TO PERFORM	B IMPAIRS CAPABILITY	C OTHER THAN ROUTINE	D ROUTINE
I COMBAT II POSITIONED III READY IV RESERVE AND SUPPORT V OTHERS	I COMBAT	1	4	11	16
	II POSITIONED	2	5	12	17
	III READY	3*	6**	13	18
	IV RESERVE AND SUPPORT	7	9	14	19
	V OTHERS	8	10	15	20

*Will be used by all activities, regardless of Force/Activity Designator, for medical or disaster supplies or equipment required immediately for prolonging life in case of critical injury, fatal disease or calamity.

**Will be used by all activities regardless of Force/Activity Designator, for individual and organizational clothing required to provide a minimum of essential clothing in the event an individual is without the clothing required.

46.50

Figure 11-10.—Uniform issue priority system.

able to justify them to the commanding officer, who is the final authority aboard for assigning priorities.

EQUIPAGE STOCK CARD AND CUSTODY RECORD

The supply officer keeps a complete record of every kind of ordnance equipage aboard whether it is on the allowance list or justified by an approved in-excess requisition. To keep this record, he uses the Equipage Stock Card and Custody Record, S. and A. Form 306 (fig. 11-11). The cards show all receipts and expenditures of equipage, and also the balance on hand. Except for certain ordnance equipage which requires no signed responsibility, each entry on the cards will be signed by the department head to show that he has received the quantity shown in the balance column. The items which require a custody signature are indicated by an asterisk on the ordnance equipage list. The cards are prepared in the supply department.

Your department head keeps a duplicate set of cards for the material assigned to his department. He is responsible for entering a record of all receipts and expenditures on his cards. Serial numbers of items having them should also be entered on the custody cards.

The department head may delegate the custody of an item of equipage to the subordinate in the department and obtain a subcustody signature from the actual custodian of the item on the duplicate of the custody card. The man who signs a subcustody card is responsible to the department head for the item of equipage. If he turns the item over to someone else he should obtain a memorandum receipt and hold the receipt until the material is returned to him.

A record is also kept of all equipage in the department which does not require custody signatures.

Equipage Custody Record, S. and A. Form 306A (fig. 11-12), is used within the department to show the location of the material and who has custody of it. This form may be used in some weapons departments in place of Form 306.

SURVEY OF ORDNANCE MATERIAL

In official Navy publications a survey is regarded as a means of establishing the reason for deterioration or loss of government property.

If material is missing, a survey is a means of finding what happened to it. If material is damaged, a survey will uncover how the damage occurred, who was responsible, and what should now be done with the material. The end result of a survey is to provide a method of expending the surveyed material from the books.

Anyone who is aware of a material condition that requires a survey may initiate action. Survey requests are normally started by the head of the department having custody of the material in question.

The originator requests a survey in ROUGH on a Survey Request Report and Expenditure form. The request must include the following:

1. Description and condition of the material.
2. Cause of loss, damage, etc.
3. Responsibility for cause or condition (if it can be determined).
4. Recommended disposition of material and action to be taken in regard to cause and responsibility.

As the initial request is forwarded via the department head and the supply officer, additional helpful information is added.

EQUIPAGE STOCK CARD AND CUSTODY RECORD NAV. S. AND A. FORM 306 (REV. 8-54)				CUSTODY SIGNATURE REQUIRED ☒ YES ☐ NO		CARD NO. GUN 5
DEPARTMENT	ALLOWANCE	STOCK NO.	UNIT	UNIT PRICE	ALLOWANCE LIST NO.	
Weapons	3	66650-254 8970	ea	\$150	GROUP	PAGE LINE
BINOCULARS, 7 x 50 serial numbers on attached list						
DATE	VOUCHER NO.	RECEIVED FROM ISSUED TO	QUANTITY RECEIVED	QUANTITY ISSUED	BALANCE	I acknowledge receipt of quantity of this article as indicated
4/29/58	053141	NSD NEWPORT	2		8	L. J. Myers Lt.
6/1/61	(SURVEY) 25	NSC NORVA		3	5	L. J. Myers Lt.
8/1/61	079825	NSC NORVA	3		8	L. J. Myers Lt.
10/1/62	INVENTORY ON RELIEF OF DEPT. HEAD				8	E. Sage Lt. (JMS)

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7.3

Figure 11-11. — Equipage Stock Card and Custody Record, S. and A. Form 306.

The purpose of this initial request is to provide all the data available to assist the commanding officer (or his delegate) in determining the type of survey if any, to be ordered.

The type of survey to be conducted may be either FORMAL or INFORMAL.

Formal Survey

A formal survey is required at all times when it appears that responsibility for lost or damaged material may be placed on a person or persons in the naval service.

In most cases, a formal survey is conducted by one officer. However in the case of surveying equipage where custodial signature is required, and when so directed by the CO, a survey board of three officers (no one of whom is from the department having control of the material) conducts the survey.

Informal Survey

As a rule, the informal survey is held for routine matters where it appears that no disciplinary action is required. The distinguishing

feature of the informal survey is that the CO appoints the head of department having custody of the material to be surveyed as the surveying officer.

After the findings have been made by the surveying officer, board, or head of department, a full report is submitted to the commanding officer for review. The supply officer and/or appropriate department head takes the final action in expending the material from the books.

Ordnance repair parts worn out or damaged in use are not surveyed when replaced by a new part, except upon order of the CO or higher authority. BuWeps requires formal survey for ordnance equipage requiring custody signature, when such equipage is missing, damaged, or worn beyond economical repair.

Repair kits are listed as one-line items and are replaced by complete kits, even though not all items in the kit were used up.

Some unserviceable items must be repaired by the manufacturers under the warranty provisions of their contract. The handling of such items and other repairable items is described in OSO Field Instruction P4440.83.

U. S. GOVERNMENT PRINTING OFFICE 16-45109-2

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the custody cards or a previous inventory—you must sight each item and determine its condition. You may have men assisting you in the work but you are responsible for the accuracy of the report you turn in.

CHAPTER 12

WEAPONS DIRECTION SYSTEM COMPONENTS

Chapter four of this course covered the flow of information in a Weapons Direction Equipment and in a Target Designation Equipment. The functions of the major units and their interrelationship were described. In this chapter we will take up the internal components and circuits of these equipments. We will use the same major units as we did in chapter four. There are, however, variations in units performing similar functions in different installations. But, fundamentally, the components and the circuitry in these units are similar, and to this extent the units we have selected are representative.

Since we are interested in the internal components, we will not concern ourselves with system operation or data flow which does not serve our discussion. Conventional circuits will not be covered. But, the circuitry of the consoles in the system is complicated by the amount of data displayed. Therefore we will review a basic PPI (plan position indicator) remote indicator to provide a starting point for our discussion.

BASIC PPI-SCOPE

A conventional PPI-scope has a two-dimensional display, indicating range and bearing in a polar coordinate system. The range sweep starts at the center of the display, which represents own-ship position; the sweep moves along a radius corresponding to the radar bearing. The indicator's range sweep is correlated with radar range by starting both range systems simultaneously. Bearing is correlated between the two by positioning the range sweep at the same bearing as the radar antenna. The PPI-scope is intensity modulated and is held far below cutoff except during the range sweep. A gating voltage is applied during the range sweep to change the bias to just below cutoff. Video signals from the radar are superimposed on

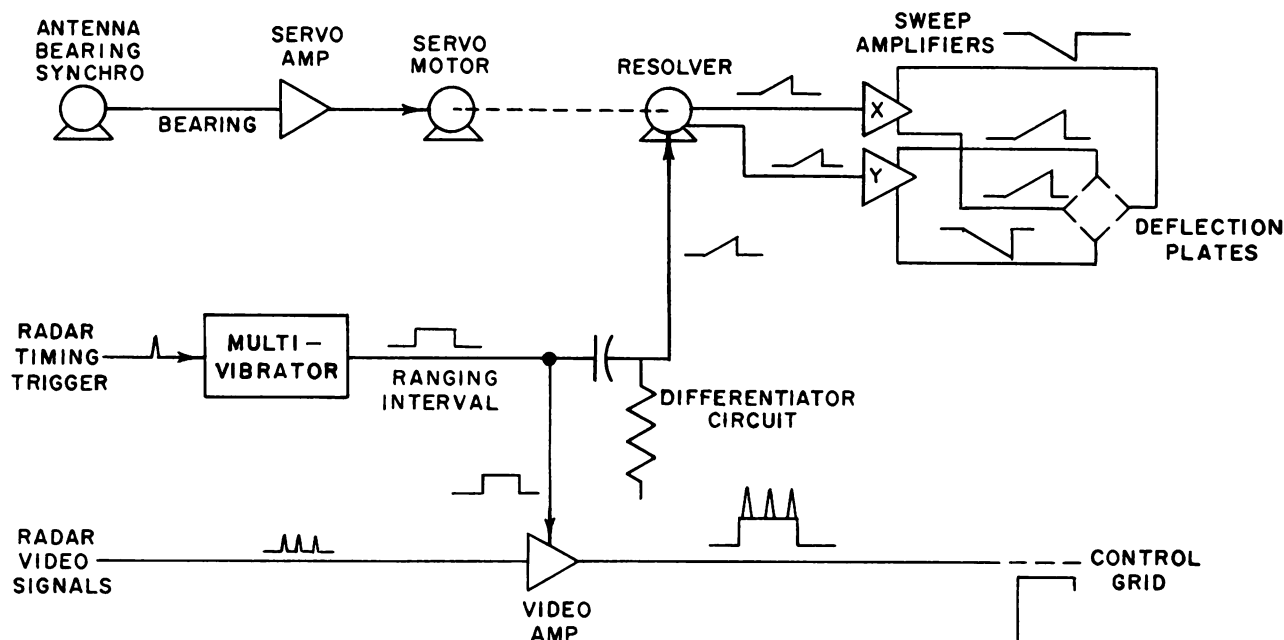
the gate voltage and will drive the tube into conduction.

TIMING CIRCUIT

A multivibrator is used to measure the passage of time and to generate the gate pulse (fig. 12-1). A trigger from the radar is applied to a monostable multivibrator, causing it to change condition. The shift in its output marks the beginning of the indicator's ranging interval. Multivibrator action causes the circuit to shift back to its original condition and terminate the ranging interval. The output is a square wave pulse whose length is determined by circuit components. The constant of the electromagnetic wave's velocity in space correlates time and range. The pulse is applied to the control grid of the scope's electron gun as the video pedestal gate.

SWEEP GENERATION

The range sweep starts in the center of the scope and moves linearly with time to its outer edge. Sawtooth voltages applied to the deflection plates deflect the electron beam from the center of the scope. To align the deflection angle of the beam with antenna bearing, we will use a resolver. The electrical input to the resolver is a sawtooth voltage. This voltage is obtained from a differentiating circuit whose input is the square wave gate pulse. The circuit's output is a sawtooth voltage which rises linearly with time for a duration equal to the ranging interval. The rotor of the resolver is mechanically positioned by antenna bearing. The outputs of the resolver are two sawtooth voltages equal to the X (sine) and Y (cosine) components of antenna bearing, and whose amplitudes are proportional to the input voltage which represents range. Hence, the resolver converts the angular bearing and the linear range voltage into sweep voltages for the X and Y axes of the



92.102

Figure 12-1. —Basic PPI scope.

display. The sawtooth voltages are amplified in separate push-pull sweep amplifiers. The two output voltages of each amplifier are applied to the deflection plates.

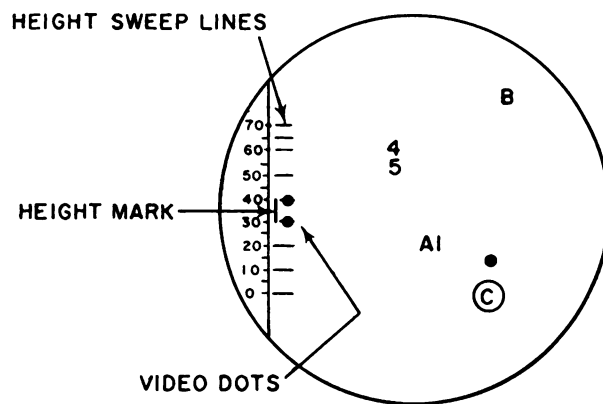
The occurrence of a video signal during the ranging interval determines the distance of the video spot from the center of the scope, while the bearing of the video indication is determined by the sweep voltages. At this point we have a basic PPI-scope with a polar coordinate display, but whose deflection system uses rectangular coordinate voltages. The explanation was greatly simplified but the basic circuits are shown. We will add a great deal to these circuits as we discuss the consoles in the equipment.

TARGET SELECTION AND TRACKING CONSOLE

We are interested in the components of a console which selects and tracks targets. We will assume the Target Selection and Tracking Console (TSTC) is connected to a three-coordinate radar, and displays the following signals, (fig. 12-2).

1. Video from the search radar
2. Video spots from the tracking channels
3. Pantograph input to a tracking channel
4. Symbols identifying the tracking channels
5. Stored height in a tracking channel

6. Height mark indicating radar accuracy
 7. Symbols of fire control systems
 8. Own ship's heading line
 9. Weapon clearance lines
- The TSTC displays this information with a single CRT which has two electron guns with



LETTERS INDICATE CHANNEL POSITION
NUMERALS INDICATE TRACKING FCS
CIRCLE INDICATES CHANNEL ACCESS
DOT INDICATES TARGET VIDEO

92.13

Figure 12-2. —Typical target selection and tracking console display.

their associated sweep and video systems. The signals are divided between the guns and are applied in a definite sequence on a time-sharing basis. The persistence of the scope gives the illusion of continuous display.

RADAR VIDEO

We will consider the PPI display (range and bearing), of radar video. This signal shares an electron gun with the pantograph position signal and video spots which represent the stored positions in the tracking channels. Each of these signals has its own sweep generating and video system. Therefore, the signals pass through electron gates which control the sequence of the signals applied to the display. We will take up the other signals and the gate circuits later; for now, we will consider only the radar video.

The interval between the radar timing triggers, T_R and T_E , is equal to the maximum range of the indicator. This interval is established in the indicator by a bistable multi-vibrator (fig. 12-3). The T_R trigger trips the

square wave pulse from the timing circuit to produce X, Y, H (height), and R (range) sweep voltages. The X sweep circuit uses $V_R \sin B_Y$, the Y sweep circuit uses $V_B \cos B_Y$, and the H sweep circuit uses $V_R \sin E$. The range sweep is used in the height display and its circuit uses the vector sum of the X and Y sweep voltages. We are interested in the X and Y sweep circuits at this particular time, but all the circuits are similar. Therefore a discussion of the X sweep generating circuit will be sufficient.

A block diagram of the X sweep generator is shown in figure 12-4. The inputs are the two square wave gate voltages from the timing circuit and the voltage $V_R \sin B_Y$. The output is a sawtooth voltage with the same duration as the range gate and a peak value proportional to the amplitude of the $V_R \sin B_Y$ signal. The sawtooth voltage is generated by the capacitor C29. The diode shorting network provides a path for the rapid discharge of C29 at the end of the gate. During the gate the short circuit is opened and C29 charges to the potential difference across the amplifier. The charge on C29 is proportional

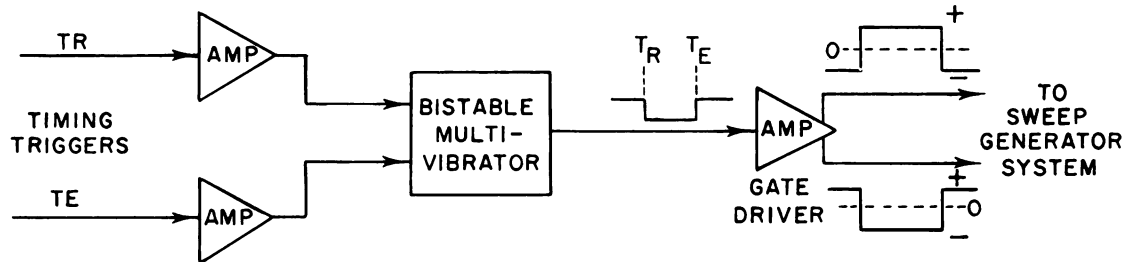


Figure 12-3.—Ranging interval.

92.103

multivibrator and the T_E trigger shifts it back to its original condition. The duration of the multivibrator's square wave output is equal to the range interval. The output of the square wave amplifier is two square wave voltages with equal but opposite swings above and below a zero reference. The two square wave voltages are applied to the radar sweep generation circuit.

RADAR SWEEP GENERATOR

The inputs from the radar to the sweep generating circuits are the $V_R \sin B_Y$, $V_R \cos B_Y$, and $V_R \sin E$ voltages. These voltages define the radar beam's position. The sweep generating circuits use these voltages and the

to the product of the amplifier's input signal, $V_R \sin B_Y$, and the gain factor of the amplifier.

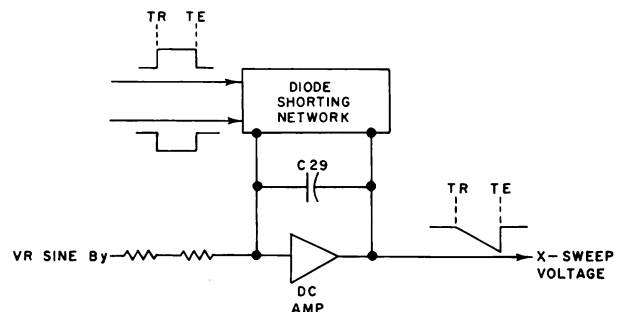


Figure 12-4.—Sweep generator circuit block diagram.

92.104

The diode shorting network (fig. 12-5) is called a Lewis gate and has numerous applications in the equipment. Diodes CR1, 2, 3, and 4, form a balanced bridge circuit. With no gate signals, the diodes are forward biased, and current flows across the bridge between the two supplies. Terminals A and C are at the same potential due to the balanced legs, and for all practical purposes are shorted together. Hence there is no charge on C29. Terminals B and D are equal in magnitude with respect to A, (R_1 and R_2 are equal), but have opposite polarities. Gate voltages, $-70V$ to CR5 and $+70V$ to CR6, back bias these diodes which isolate the gate circuits from the bridge circuit. But when the gate pulses shift polarity, CR5 and 6 become forward biased, and current flows between the bridge and gate circuits. This current causes CR 1, 2, 3, and 4 to become back biased, and isolate terminal A from C. Thus for the duration of the gate pulses the short circuit is removed and C29 takes on a charge. The linear charging current of the capacitor produces the sawtooth voltage output. When the gate circuit reverts to its original state, CR5 and 6 are again back biased, and C29 is shorted by the bridge and discharges.

PPI SWEEP DEFLECTION

We have assumed that the radar X and Y sweep voltages are applied to the sweep deflection system of one of the electron guns. Before entering the amplifiers in the system the sweep voltages pass through a range scale shift circuit. This circuit varies the resistance in series with the amplifiers and in effect varies their gain factor. The range scale is shifted so that the area represented by the display can be expanded or reduced.

The CRT has two electron guns, each located slightly off center. Since the center of the tube is zero range, compensation must be made for the offset of the guns. Compensation is made by varying the negative feedback in the X sweep amplifiers. A diode is placed parallel to one of the series resistors in the feedback circuit. When the X sweep input voltage to the amplifier is positive, the output is negative and the feedback diode is back biased. In this condition the diode does not affect the feedback circuit. But if the input signal to the amplifier is negative, the output is positive and the diode is forward biased. When the diode is forward biased it shunts out the series resistor and increases the

amount of feedback in the amplifier. The feedback reduces the gain of the amplifier in one direction of the X sweep more than in the other direction.

The sweep voltages corrected for the range scale are applied through a gate circuit to the deflection plates of the CRT. Since other signals must also pass through the gate circuit we will cover the signals first.

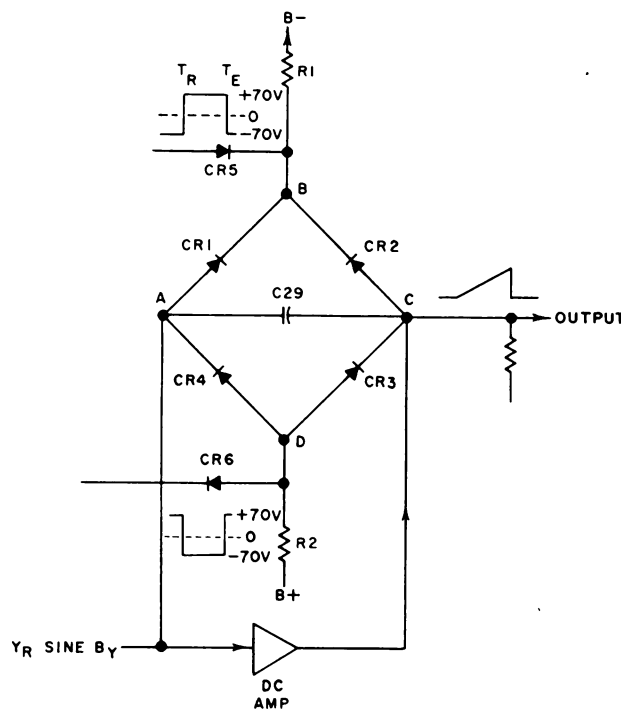


Figure 12-5.—Diode gate.

92.105

VIDEO SIGNAL

The CRT is intensity modulated. A video pedestal pulse is applied to the electron gun during the ranging interval between the T_R and T_E triggers. This interval is modified in the video system. The range sweep is prematurely blanked in a section of the display to make room for the height display. This modification is called the X sweep cutoff. At low elevation angles the start of the range sweep is blanked to eliminate sea return. When this is done the video is called sky video. We will take up the modifications before the pedestal pulse.

X Sweep Cutoff

A second electron gun in the CRT is used to display height, and a small section of the PPI

display is blanked to furnish the necessary space. The height display is located along the outer edge of the left-hand side of the scope. Since the presentation is normally oriented so that the top of the tube represents true north, this represents an area to the west. The PPI range is blanked at its outer extremity when the bearing sweep places it in the western section of the scope. The X sweep voltage controls the bearing sweep along the east/west axis of the display, and is proportional to the signal $V_R \sin B_Y$. Hence the sign of the X sweep voltage varies as the sine function of B_Y , and is negative in the left-hand quadrants of the display. The sweep voltage is applied to a monostable multivibrator. When it is negative and of sufficient magnitude it will trip the multivibrator. The multivibrator's output is a sharply rising pulse which is applied to the video pedestal to blank the tube. When bearing leaves the western quadrants, the X sweep voltage swings positive and the full range interval is displayed.

Sky Video

Short-range video is blanked at low elevations to eliminate sea return. The voltage $V_R \sin E$ is proportional to antenna elevation. This voltage is always positive, and its magnitude varies directly with elevation. The voltage is applied to a bistable multivibrator. When elevation is above the angle at which short-range video is blanked, the output of the multivibrator is maximum positive. The multivibrator is held in this condition by the voltage $V_R \sin E$. When the magnitude of this voltage drops below a value determined by circuit components, the multivibrator shifts condition and its output becomes maximum negative. The output is applied to a monostable multivibrator. The input to this multivibrator is the T_R timing trigger. The T_R trigger will not shift the multivibrator unless the low elevation bias voltage is present. When this occurs, the output of the multivibrator is a negative pulse for each T_R trigger. The duration of the negative pulses is determined by circuit components. These negative pulses blank video signals received at short ranges and low elevations.

Video Pedestal Pulse

The video pedestal generator is a multivibrator which is controlled by the timing

pulses T_R and the modified T_E . The multivibrator's output is a square-wave pulse with a duration corresponding to the video display time. The pedestal pulse is applied to a gating circuit. The other inputs to the pedestal gate circuit are video signals from the search radar via an amplifier, and channel spot brightening pulses from the sweep system. The pedestal gate output consists of a series of pedestal pulses with video signals superimposed on the pulse and channel spot brightening pulses between the pedestal pulses. The output is applied to the control grid of the electron gun via a video amplifier and a d-c restorer circuit. The d-c restorer couples the signals from the amplifier to the electron gun while isolating the high voltages of the gun from the amplifier. We will consider the channel spot brightening signal later in the chapter.

At this point we have a bias PPI remote indicator which displays the range and bearing of video signals. Space has been saved in the scope for a height display. We have disregarded the pantograph and channel spot position signals to the PPI-scope and the gating circuits which control the sequence of the signals displayed. We will cover the origination of these signals, and then the gating circuits.

PANTOGRAPH

The range and bearing of targets selected for tracking are obtained from the polar coordinate PPI display. This information must be accurately measured and converted to rectangular coordinates represented by electrical voltages for the tracking system. The pantograph (fig. 12-6) translates motions of its arms into linear components along the X and Y axes of the display, and converts the linear motions into electrical signals. The movement of the arms is connected to the linkage parallelogram so the point P' in the illustration will follow point P . A pin at point P' engages two scotch yokes, which separate any motion of point P' into X and Y components. A rack and pinion gear assembly on each yoke drives its associated potentiometer shaft. The mechanical arrangement of the scotch yokes is identical to the scotch yoke (rack) assembly of a conventional component solver.

The potentiometers are part of identical voltage divider circuits. Two equal voltages, one negative and one positive, are applied to

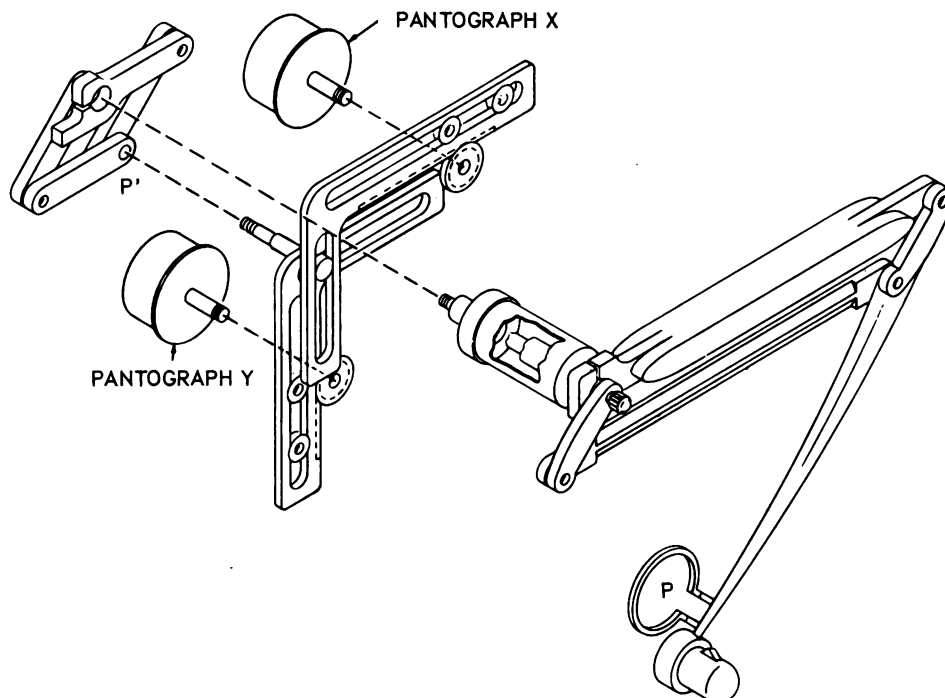


Figure 12-6.—Pantograph.

92.106

the circuit. Thus the potentiometer output may be negative or positive, depending on the position of the pantograph arms. When the pantograph is positioned at the center of the display the outputs of the potentiometers are zero. When the pantograph is positioned at maximum range to the east or north (X and Y, respectively), the output voltages are maximum positive. It follows that for maximum range west or south the output voltages are maximum negative.

The pantograph X and Y voltages are connected through a range-scale switch to identical amplifiers. The range-scale switch keeps the pantograph voltage scale factor compatible with the other deflection voltages. The outputs from the amplifiers are connected to data insertion circuits for display, and to the tracking channels.

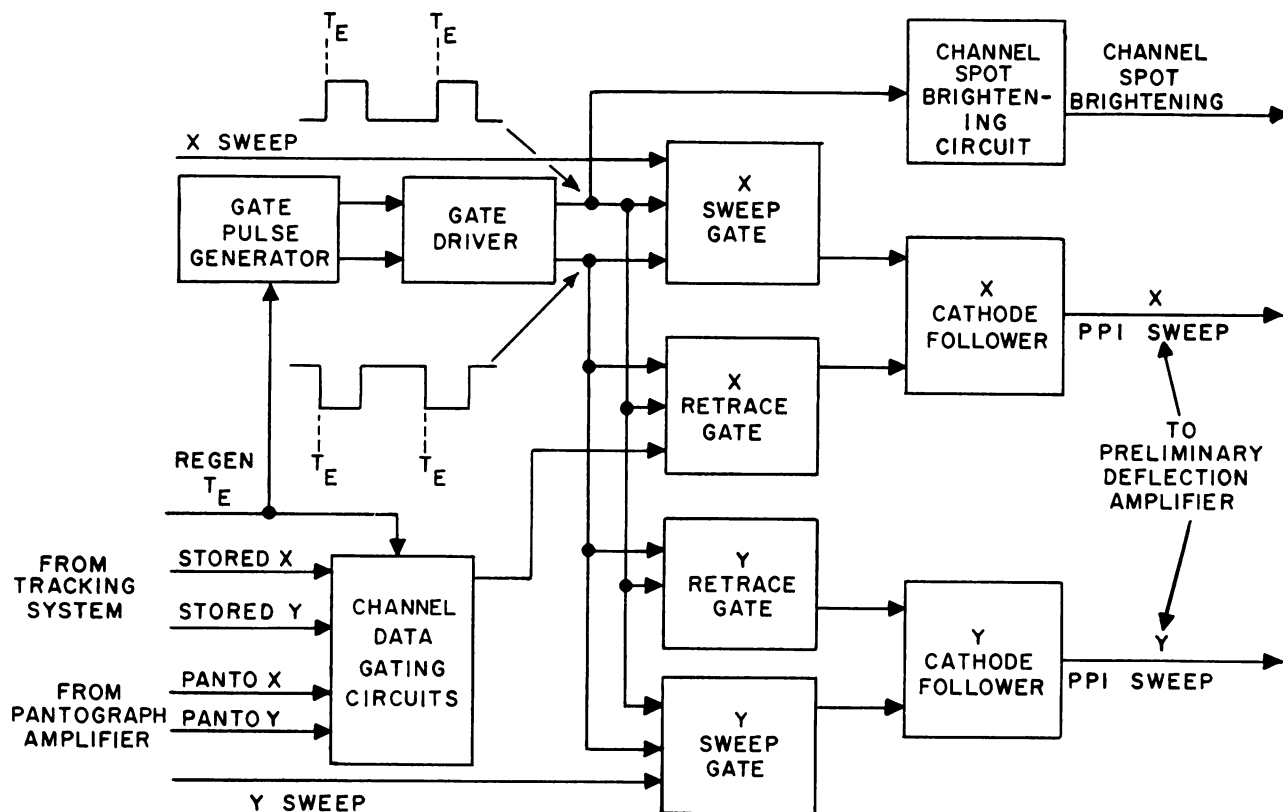
CHANNEL SPOT POSITION

Channels in the tracking system assigned a target receive X and Y position information from the pantograph. This information is used to establish tracking rates and to generate a

continuous target position. The generated target position in each channel is fed back to the PPI display for comparison with radar video. The voltages to position the channel spot are equal to the target position voltages, and thus are available. These voltages are connected to the data insert circuit, where they wait their turn to be displayed. We will cover the tracking system and the stored height data in the system later.

ELECTRON GATE RETRACE INSERT

In a conventional indicator, only the ranging interval is used for display; during retrace time the tube is blanked. Retrace time in the TSTC is relatively long due to the difference between the maximum range of the radar and the indicator. The TSTC uses this time to insert the pantograph position and the stored positions in the tracking channels into the display. During the ranging interval the radar's sweep voltages are applied to the deflection system (fig. 12-7). The T_E trigger which marks the end of the ranging interval closes the X and Y sweep gates and opens the X and Y retrace gates.



92.107

Figure 12-7.—Retrace insertion gate circuit.

While the retrace gates are open, sweep voltages from the channel data gating circuit are applied to the deflection system and a brightening voltage is applied to the video system. After a short period the retrace gates are closed and the radar gates are opened.

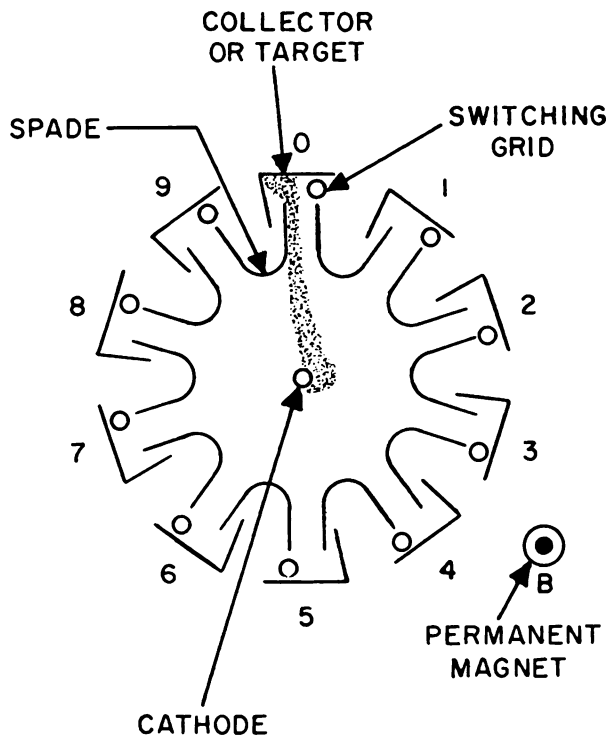
The sweep gates are controlled by a multivibrator in the gate pulse generator. The T_E trigger shifts the multivibrator whose outputs are two square-wave pulses. These pulses are amplified in the gate driver and have equal excursions above and below a zero reference. The square-wave pulses control the operation of the gates. The gates are balanced bridge diode circuits—Lewis gates—which were explained previously.

When the retrace gates are open the sweep voltages from the channel data gating circuit are applied to the display. The channel data gating circuit changes the source of the sweep voltages supplied to the gates. The sources of the sweep voltages are the tracking channels and the pantograph position signal. In other words,

for each retrace time a different set of sweep voltages is applied to the display. A special device called a beam-switching or beam-stepping tube is used to control the switching in the circuit. We will cover the beam-switching tube and then the operation of the circuit.

Beam-Switching Tube

The beam-switching tube depends on the effect of crossed magnetic and electric fields for its operation. Its principles of operation are similar to those of the magnetron. An electron in crossed electric and magnetic fields moves in a curved path. If the strength of the crossed fields is properly adjusted, an electron will have an average motion along a line of constant potential. The beam-switching tube has a cathode in the center with ten arrays in a circle (fig. 12-8). Each array consists of a spade, a collector or target, and a grid. A magnet around the envelope of the tube produces a longitudinal magnetic field within the tube. When the tube is



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Figure 12-8. —Beam switching tube.

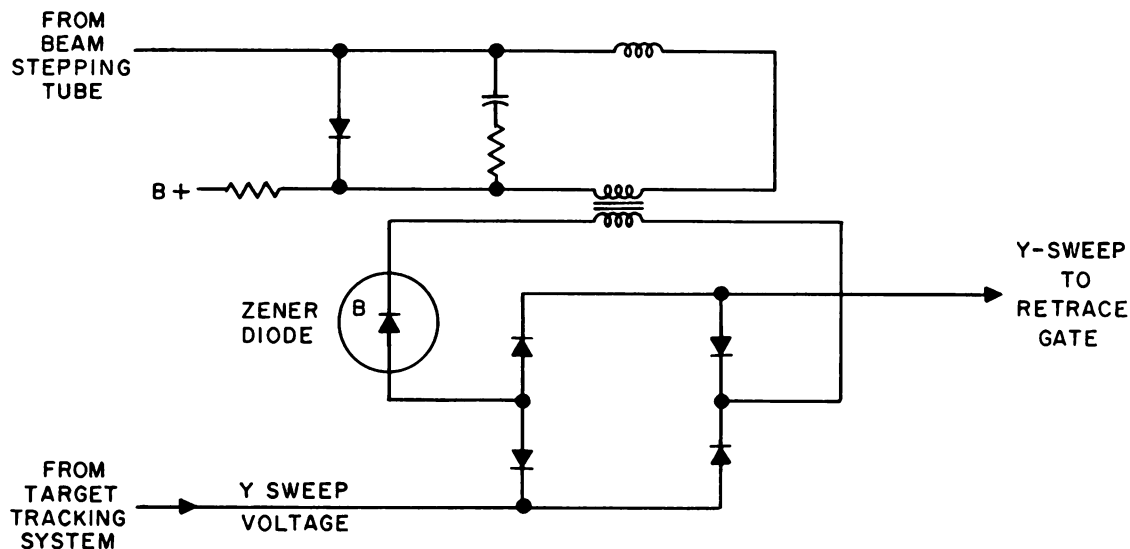
turned on, all the spades and collectors are at equal potentials and are positive with respect to the cathode. In this condition the electron beam from the cathode is not connected to any of the arrays. To start the tube's switching action the potential of one of the spades is lowered. This distorts the potential lines in the fields and the electron beam from the cathode follows a curved path along a constant potential line to the array with the lowered spade potential. Some of the electrons are absorbed in the spade, but most of them reach the collector. Current flow through the external circuits keeps the spade and collector at a reduced potential, and locks the electron beam to that array. To switch the beam to another array, the potential on the grid of the conducting array is lowered from a positive value to near zero. This distorts the electric field in its vicinity and causes the electron beam to strike the spade of the adjacent array. The spade potential of that array is lowered due to its current flow, and the spade potential of the original array is raised due to the reduction of its current flow. The result is that the electric field lines shift; this in turn results in the beam locking on to the new array.

Switching in the tube is very rapid and is a result of a change in potential on the switching grid. In this application of the tube, all the even-numbered grids are connected together, as are the odd-numbered grids. The grid potentials are controlled by a bistable multivibrator. The T_E pulse shifts the multivibrator between its two states. This in turn shifts the potential on the grids and rotates the beam in a clockwise direction to the next adjacent array. Thus the T_E pulse switches the electron beam consecutively through all the arrays.

The beam-switching tube is not self-starting. The switching action is initiated by a starter tube. When the power is first applied the starter tube conducts and reduces the spade potential on the number 1 array. The electron beam in the switching tube is formed, and locks on to this array. Current flow through the beam-switching tube cuts off the starter tube.

CHANNEL DATA GATING CIRCUIT

The collectors in the beam-switching tube are connected to channel data gating networks. One network is associated with each tracking channel and one with the pantograph. Each network contains identical gating circuits for the X and Y sweep signals. Therefore only the Y sweep gating circuit need be discussed. The Y sweep signal from the channel is blocked from the retrace gate by the back-to-back diodes in this gate (fig. 12-9). But when the electron beam in the beam-switching tube is locked on to the collector connected to this circuit, current flows through the primary of the transformer. Current flow in the secondary is blocked by the series zener diode. When the voltage across the zener diode reaches the zener voltage (breakdown voltage) the current increases very rapidly while the voltage drop across the diode remains almost constant. This current flow is sufficient to forward bias the conventional diodes in the circuit. The circulating current in the transformer circuit forward biases the diodes. Thus, as long as the beam-switching tube stays locked on this collector, the position signals can pass through the gate. When the electron beam in the tube moves to the next collector, the next gate is opened and the original gate is closed. All the X output terminals of the data gating circuit are tied together, as are all the Y output terminals. These terminals are connected to the X and Y retrace gates, respectively. When these gates are opened by the square-wave pulses



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Figure 12-9.—Channel data gating network, simplified schematic.

from the gate drive (fig. 12-7), the channel position signals pass through to the deflection system.

As shown in figure 12-7, the positive square-wave pulses from the gate drive are also used to produce the channel spot brightening pulse. This pulse is supplied via a gating circuit to the control grid of the electron gun to drive the tube into conduction. Since the position and brightening signals are gated by the same pulse, their arrival in the CRT is coordinated.

When a channel is not assigned a target, the tracking system substitutes parking voltages for the position signals. The parking voltages are large enough so that the spot associated with that channel will be deflected off the screen. Thus, unassigned channels are not displayed.

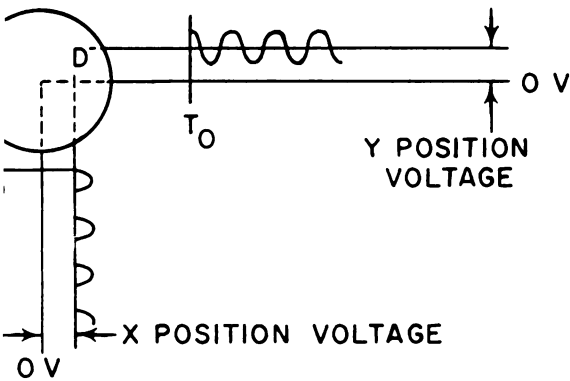
SYMBOL AND HEIGHT SYSTEMS

The other electron gun in the CRT is time shared by the symbol and height systems. We will first consider the symbol system. The start of the system is symbol generation. Later we will take up their sweep and video circuits, dividing them into PPI symbols and height symbols. We will not cover all the symbols, but select representative ones. Next we will discuss the height display.

SYMBOL GENERATION

The symbols used in the display are letters, numbers, straight lines, circles, and arrows. These symbols are traced on the screen by the beam from the electron gun. A straight or a curved line can be traced at any angle if voltages with the proper phase and amplitude are applied to the deflection plates. Any desired symbol can be traced by a combination of deflection voltages which will produce curved and straight lines. For example, when a sine wave is applied to the horizontal plates and another sine wave of equal amplitude, but shifted 90° in phase, is applied to the vertical plates, a circle is traced. If the horizontal plates are supplied by a half-wave rectified voltage, a well formed "D" will be traced (fig. 12-10). Complex symbols are made up of more than one set of deflection voltages, but the adjacent lines appear to be one trace.

The symbol generating circuits consist of wave-shaping networks. An oscillator supplies the circuit with an audio-frequency voltage. In addition, d-c voltages to position the symbol are inputs to the network. For example, the stored position voltages in tracking channel "A" are the input to the symbol "A" circuit. The stored position voltages are those used to position the channel spot. The outputs of the symbol generating circuits are the d-c position voltages with the modifying symbol waveforms superimposed.



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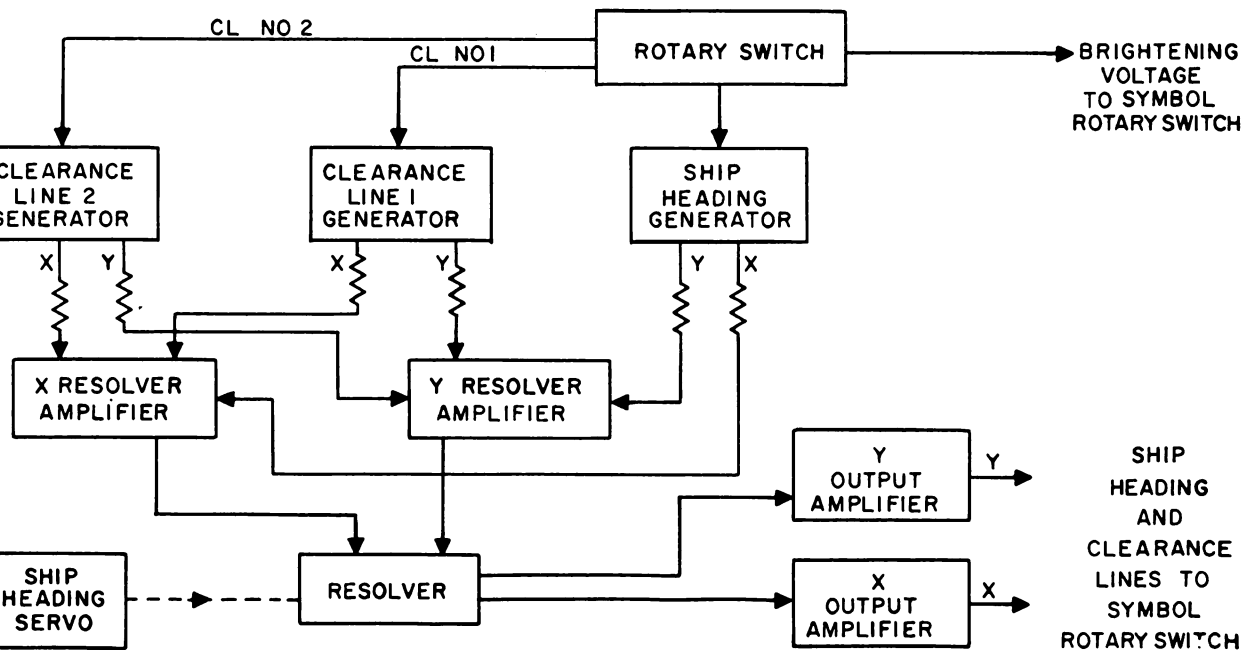
Figure 12-10.—Generating the letter "D".

rotary switch driven by a constant-speed motor sequentially connects the symbol signals to the deflection system of the display. A brightening voltage is applied via the rotary switch to the control grid of the electron gun to drive the tube into conduction. The rotary switch synchronizes the brightening voltage input with position voltages. Each symbol is displayed in an equal period. Consequently, a complex symbol is traced by the beam fewer times than a simpler symbol. To obtain equal intensity for the symbols, the brightening voltage supplied

for a complex symbol is larger than for a simple symbol. To call attention to a particular symbol, an overbright voltage is substituted for the normal voltage. To produce a flashing symbol the brightening voltage is interrupted by a relay.

Ship Heading and Clearance Lines

An electronically generated line indicates ship heading and orients the display to the north. Once each revolution of the symbol rotary switch a trigger voltage is supplied the ship heading line generator. The trigger (fig. 12-11) is shaped into a trapezoidal waveform which will produce a linear sweep in the display. The voltage is divided into two separate voltages of equal magnitude in a voltage divider. The magnitude is proportional to the length of the ship heading line traced on the scope. The two voltages are applied to a resolver via the X and Y driver amplifiers. The rotor of the resolver is positioned by ship heading. The stator position represents north in the display. Since the input voltages are equal, the resolver outputs are proportional to each other and to the sine and cosine functions of the rotor angle. The outputs of the resolver are amplified and applied to the X and Y deflection plates. The trapezoidal shaped voltages produce a straight line when



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Figure 12-11.—Ship heading and clearance lines, simplified block diagram.

traced on the scope. The resolver has modified the input voltages so that the trace is aligned with ship's bow and is a measure of ship heading in the display.

Weapon clearance lines are generated which indicate the blind zone for missile firing. The clearance lines are measured with respect to the ship's bow. A trigger voltage is supplied during the revolution of the rotary switch for each clearance line. The trigger voltage is applied to a phase inverter whose outputs are two voltages with equal maximum excursions but of opposite polarities. The two voltages are the inputs to the X and Y driver amplifiers which are time shared with ship heading line generation. But the clearance line voltages pass through unequal resistors in series with the amplifiers. Thus the inputs and hence the outputs of the X and Y amplifiers are unequal. The outputs are applied to the X and Y deflection plates via the own ship heading resolver. The resolver orients the clearance line to ship's bow. The unequal magnitudes of the X and Y voltages cause the clearance line to be offset from the bow by an amount proportional to the difference in magnitudes.

Height Symbols

The height display is always associated with the channel of access. The stored height in the channel is displayed as a vertical line called the height mark. The length of the height mark varies directly with stored range to indicate the uncertainty of height data due to the increase in beam width as range increases. Target height is measured by a spot in the display which is positioned by the height cursor.

Height is displayed in the section of the scope left blank by the X-sweep cutoff of the PPI sweep. Since the height symbols are always in the same position with respect to the X axis, their X-sweep voltage is obtained from a voltage divider. The height cursor spot is positioned in the Y axis of the display by a deflection voltage picked off a voltage divider circuit. The amount of voltage picked off is determined by the height cursor control knob, which is positioned by the operator.

The height mark is positioned in the Y axis by a d-c voltage which is proportional to the stored height. The length of the mark is varied by superimposing an audio-frequency symbol generating voltage on the position voltage. The audio-frequency voltage is applied to a diode

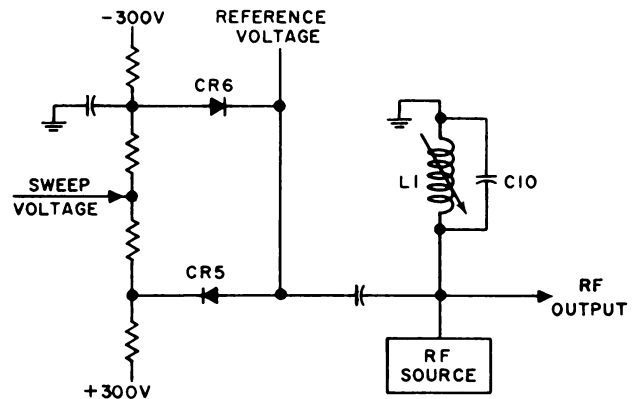
circuit which is biased by a voltage proportional to range. The audio-frequency output voltage is proportional to range and is superimposed on the height mark position voltages.

HEIGHT VIDEO

The height display presents a cross-sectional view of the space around the stored target position. The dimensions of the displayed area are controlled by a range gate comparator and an XY gate comparator. The gate comparators establish the relationship between the selected area in which height is displayed and the actual position of the radar beam. Height is displayed during the time the radar beam is within the selected area. At other times height video is blanked and symbols are displayed.

The range gate comparator compares a range sweep sawtooth voltage whose maximum amplitude is proportional to the maximum range of the indicator with a voltage which represents stored range in the tracking channel. When the sweep voltage (radar range) is within a specified limit of the stored voltage (target range) the gate is opened. Inputs to the XY gate comparator are voltages representing the X and Y stored position and the X and Y sweep voltages representing the actual position of the radar beam. The gate is opened for the height signals when the sweep voltages are simultaneously within specified limits of the channel voltages.

Figure 12-12 shows the X-gate comparator circuit. The Y and range gate circuits are similar and will not be discussed. The r-f input provides a carrier voltage for the gate pulses. The two diodes, CR5 and CR6, are in parallel with the r-f tank circuit L1 and C10. The diodes



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Figure 12-12.—Comparator gate.

are back biased by the negative and positive supplies and thus isolate the r-f source side of the tank circuit from ground. The stored position voltage is applied to one side of the diodes and the radar sweep voltage to the other. Hence the bias of the diodes is determined in part by the potential difference between these two voltages. One of the diodes will become forward biased and will conduct when there is a large difference between the two voltages. If either diode conducts, it will connect the source side of the r-f tank to ground and the r-f output will drop to zero. The output signal is present only when the radar beam position is within specified limits of the stored position. The r-f output pulses are detected and rectified. The rectified signals are square-wave pulses which control height-symbol video and sweep-circuit gates.

Height Video Sweep Voltages

The X-sweep voltage for the height video display is generated by a monostable multivibrator. The input to the multivibrator is a square pulse from the range gate comparator. The duration of the pulse is equal to the height range gate. The pulse shifts the multivibrator to produce an output voltage whose magnitude is determined by the circuit components and whose duration is equal to the range gate pulse.

The radar provides a voltage, $V_R \sin E$, which is used as the Y-axis height sweep voltage. The quantity V_R is a constant value equal to the maximum slant range of the indicator. Since the voltage varies as the sine function of elevation, the height sweep time varies indirectly with elevation. At large elevation angles the sweep voltage is large and the time required for a complete sweep is reduced. This is reasonable, for as elevation increases, the slant range to the maximum height of the indicator decreases. Since the sweep is a function of the indicator's maximum slant range and the variable angle of elevation, height video signals will occur in the sweep at a time proportional to target height. The height sweep sawtooth voltage is generated in a Lewis gate circuit (previously explained, and illustrated in figure 12-5).

SYMBOL-HEIGHT GATE

The gate generator (fig. 12-13), connects either the symbol or the height signals to the CRT. The range comparator output square wave

represents the interval of the range sweep during which we wish to display height video. The square wave pulse controls four Lewis gates through a multivibrator. The gates are divided into two pairs; one pair handles the X deflection voltages, the other pair the Y deflection voltages. When the range comparator pulse is not present, multivibrator action opens gates Z1 and Z2 (symbol X and Y voltages) and closes gates Z3 and Z4 (height X and Y voltages). The range comparator pulse shifts the multivibrator and reverses the gate conditions.

The circuit to the control grid of the electron gun contains gates to provide a sequence to the height video and symbol brightening signals. When both the X and Y sweeps are within the specified limits of the stored position, the XY comparator indicates this by square-wave pulses. These pulses are one of the input signals to the coincident video unblank amplifier. The other input is the positive square-wave pulse from the range comparator which indicates the range sweep is within the specified limits of stored range. When the two pulses are present simultaneously in the amplifier, a video unblank pulse is produced. The range comparator pulse is also used to produce a symbol blank pulse. The symbol blank pulse changes the bias of the symbol gating amplifier to below cutoff and the brightening voltage is dead ended. The range comparator coordinates the timing of the signals passing through the gates.

TRACKING SYSTEM

The search radar's antenna rotates in bearing and thus measures target position intermittently. The WDE tracking system generates a continuous target position to help the fire control system acquire the target. The tracking system stores (memorizes) the position of selected targets in the X, Y and H coordinates. The pantograph and height cursor circuits furnish the position data. The tracking system computes rates of target movement in the X and Y coordinates, and these rates are used to generate a correction to the stored position. A rate is not computed in height due to the lack of accuracy in height determination.

Access switching temporarily connects the pantograph and height cursor circuits with a channel and connects the channel's outputs with the display and target evaluation circuits. Control circuits operate relays which open, close,

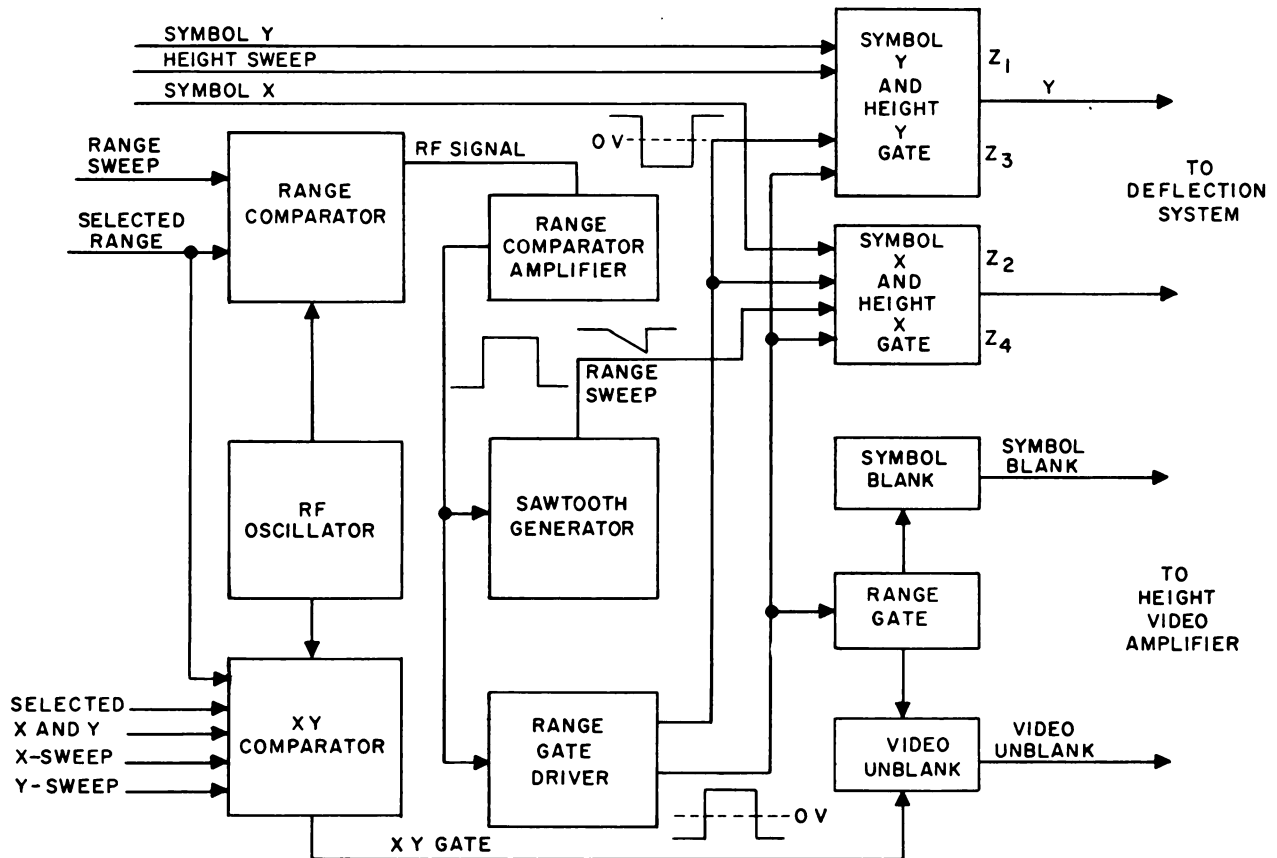


Figure 12-13.—Symbol-height gate generator.

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or switch data-carrying circuits in accordance with a built-in sequence of logical events. Although the relay circuits are extensive, you can readily visualize their functions if you have a good understanding of the basic "And," "Or," and "Not" logic circuits. These circuits are covered in the Basic Electronics course. Since the relay circuits vary between installations we will not cover them here.

STORAGE CIRCUITS

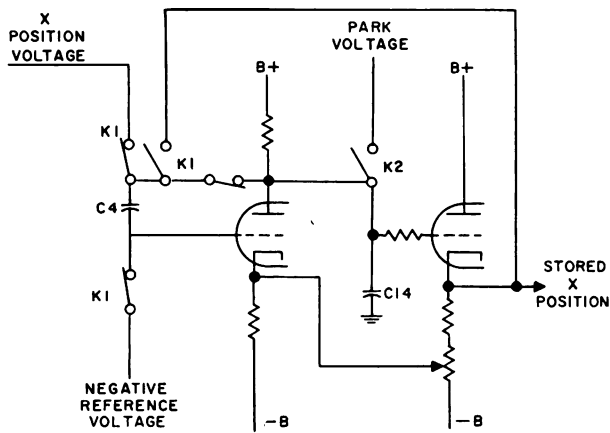
Storage circuits depend on the retention of a charge by a capacitor. This method of storing data is familiar to you; many FC radars use it to store tracking rates for coast operation. The X, Y, and H storage circuits all use this method; only the X circuit will be discussed here. The H storage circuit, however, does not have a rate or a park voltage input.

The X-position voltage from the pantograph is the input through access relays to the storage

circuit (fig. 12-14). The relay circuits are simplified in the diagram. The park voltage relay is energized when the channel is not assigned. This circuit provides a signal to position channel indications off the scope. When the relays are as shown, the position voltage input is applied to one side of capacitor C4. The grid side of C4 is connected to a reference voltage. The reference voltage maintains the grid of the tube and one side of C4 at a given level. Thus the position voltage either increases or decreases the charge on C4 as measured with respect to the reference. C4 rapidly charges to this level. C14 is also connected to the position voltage input, and it will also charge to the input voltage.

When the channel loses access, the relay shifts and causes the following changes in the circuit:

1. The input and reference voltages are disconnected from C4.



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Figure 12-14.—Storage circuit simplified diagram.

2. C4 is isolated and cannot discharge. The charge on C4 is the stored position and is connected to the output circuit.

3. While the relay is shifting, C14 momentarily maintains the conduction of the cathode follower at a level proportional to the X position voltage. After the relays have shifted, C4 is connected directly to the output cathode.

RATE CIRCUIT

The X-rate is computed by dividing the difference between the stored and the new position of the target by time. The time factor is equal to the elapsed period between times of access to the channel. The stored position voltage is applied to the cathode and the new position voltage to the grid of a tube whose plate supply is at the rate circuit's reference level. Hence variations of the plate from the reference is determined by the difference between the position voltages. This difference is proportional to target displacement. The plate voltage is applied to one side of a capacitor. The other side of the capacitor is at the reference level. When there is no rate, both sides of the capacitor are at an equal potential. A charge on the capacitor is proportional to the change of target position for a definite time and thus represents a rate of movement. The charge is transferred to separate capacitors for storage. Relays isolate the capacitors and the charge is retained.

The rate voltage is transmitted to the position storage circuit where it integrates the stored position to correct it at the computed rate. A variable percentage of the displacement

error is used by the rate computer. A rotary switch which advances one position for each rate computation varies the amount of resistance in series with the stored position input. A large percent of the voltage is applied to obtain a rapid approximate solution to the rate problem. The percentage is reduced in subsequent computations to obtain a smooth accurate solution. The stored rate is transmitted to the director assignment equipment while the stored position is transmitted to the display system in the TSTC and to the director assignment equipment. We have covered the use of the position voltages in the TSTC display. We will now consider the director assignment equipment.

DIRECTOR ASSIGNMENT EQUIPMENT

The major units of the director assignment equipment are the director assignment console, the target evaluation system, the director-channel switching, and the data conversion systems. The operation and display of the console are covered in chapter 4 of this course. The components and circuits of the console are similar to those already covered in the TSTC. Consequently, we will start this discussion with the target evaluation system.

TARGET EVALUATION SYSTEM

The target evaluation system has a separate computing channel for each tracking channel. The computing channels are identical; they predict the time available to designate the target to a missile fire control system. Target position defined by the X, Y, R, and H coordinates along with the stored rates $\dot{X}$ and $\dot{Y}$ are inputs to the computing channel from the tracking channel. The computer solves for target course and speed, which are used to predict the time factors.

Target Course and Speed

Rates $\dot{X}$ and $\dot{Y}$ are a function of target course and speed. Hence we know the values of two sides of a right triangle whose hypotenuse is equal to the target vector. The rate voltages are applied to functional potentiometers whose outputs are proportional to the sine and cosine functions of the wiper arm angle. The wiper is driven by the target course servomotor. The truth is that we don't know target course (CT),

but we will find it in a minute. The outputs of the potentiometers are $\dot{X} \sin CT$, $\dot{X} \cos CT$, $\dot{Y} \sin CT$, and $\dot{Y} \cos CT$. The voltages $\dot{X} \cos CT$ and $\dot{Y} \sin CT$ are applied in opposition to the CT servoamplifier. The CT servomotor drives the arms of the potentiometers until the two voltages cancel. When $\dot{X} \cos CT - \dot{Y} \sin CT = 0$ the servomotor is positioned at an angle equal to CT.

The other outputs of the functional potentiometers, $\dot{X} \sin CT$ and $\dot{Y} \cos CT$, are used to solve for target speed. Here again we know two sides of a right triangle but now we wish to know the hypotenuse (target vector length). The hypotenuse is equal to the sum of the voltages $\dot{X} \sin CT$ (which equals $\frac{X^2}{V_T}$) and $\dot{Y} \cos CT$

(which equals $\frac{Y^2}{V_T}$). We end up with

$$\frac{X^2 + Y^2}{V_T} = \frac{V_T^2}{V_T} = V_T.$$

The quantity V_T equals target speed in the slant plane; but target horizontal speed, V_H , is used in the predictions. To obtain the horizontal component of target speed, the cosine function of the elevation angle is used. But first we must solve for the elevation angle, since it is not an input. Height and slant range, two sides of a right triangle, are known. The range voltage is applied to a sine function potentiometer whose wiper arm is driven by the elevation servomotor. The output of the potentiometer is a voltage proportional to $R \sin E$. This voltage is the input to the elevation servoamplifier in opposition to the height voltage. The elevation servo drives until $R \sin E - H = 0$ at which time the servo-system is positioned at the elevation angle. This is the same method we used to solve for CT.

The elevation servo also drives the wiper arm of a cosine function potentiometer. The input voltage to the potentiometer is target speed V_T . The output is $V_T / \cos E$, which is equal to V_H .

Evaluations made in the computer are based on target position and motion with relation to ship position and weapon capability. But V_H is measured within the X and Y axes and is not aligned with either axis. The axes are rotated through the angle CT so that the V_H vector is aligned with the new Y axis which is called the

Y_R axis. The new X axis is called the X_R axis. This is done so that target motion can be projected along a line which coincides with an axis of the coordinate system. As you will see later, this will greatly simplify the evaluation solution. The X and Y axes are rotated through the angle CT by a resolver.

Time Factors

The evaluation computer supplies two time outputs, T max and ΔT . T max is the time required for the target to fly from his present position (which is zero time) to the last position where designation will result in interception. T max then is the total time available to engage the target. ΔT is the time the target is within the firing range of the missile. ΔT is measured from a point where designation will result in target interception at maximum missile range. This point is called T min. T min indicates the earliest possible instant that a target can be designated to a FCS and fired upon without time wasted due to the target being out of range. The solution of ΔT assumes there is no delay in the sequence of events leading up to missile firing. There are inherent delays in the system, which we will take up later.

T max and ΔT are determined by projecting target motion along a track which coincides with the Y_R axis (fig. 12-15). The track is based on the assumption that the target will maintain the computed course and speed. Target's present position, which is where the track starts, is defined with relation to the ship by the X_R and Y_R components of slant range. These components are modified by the cosine function of the elevation angle to obtain their horizontal range components. Two cosine function potentiometers are used. Their outputs are $X_R \cos E$ and $Y_R \cos E$. The track is projected in a plane parallel to the horizontal plane for the same reasons the FC computers make their predictions using the horizontal plane. Recall that we have solved for target horizontal speed V_H .

The $Y_R \cos E$ component establishes the starting point of the track. The V_H vector is in this axis, and therefore the $X_R \cos E$ component is constant. Hence we can use $X_R \cos E$ to establish a second point along the track. This point represents the target's closest point of approach to the ship, (CPA). But T max and ΔT are affected by the missile's maximum range and its time of flight. The point where the

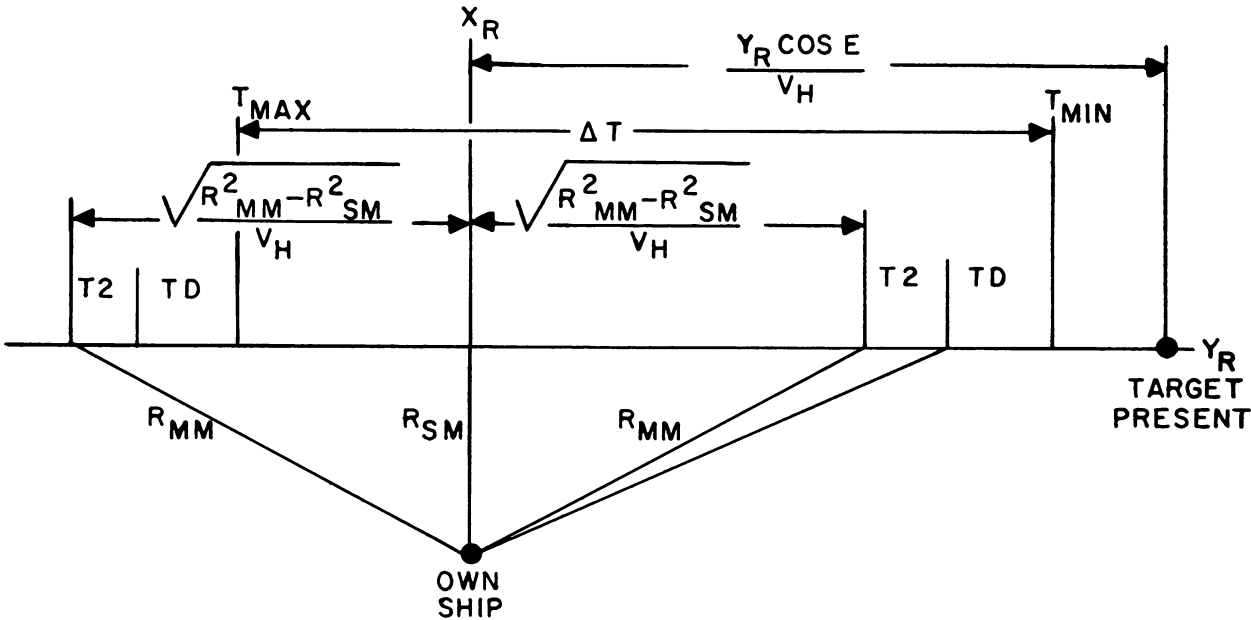


Figure 12-15.—Projected target track.

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missile trajectory for its maximum range will intersect the track is affected by the height of the plane containing the track. Consequently the effects of the missile's maximum range and time of flight are computed in a slant plane containing the track. This plane is established by computing the slant range (RSM) to the target's predicted CPA.

A right triangle with two known sides can be constructed to obtain RSM. The sides of the triangle are stored target height and the horizontal component $X_R \cos E$. Therefore, the hypotenuse is RSM, which is the predicted minimum slant range of the target. Thus we have established a second point in the track and determined the track's location with relation to own ship. The track is at target height and parallel to the horizontal plane. With this much established we can solve for T max, total time available for designation and ΔT .

The track represents target travel; hence its length is a function of time and velocity. The distance between the target's present position and the predicted CPA is equal to $Y_R \cos E$; the CPA is the crossover point of the target track. The time it takes the target to travel

this distance is equal to $\frac{Y_R \cos E}{V_H}$. V_H is equal to target horizontal speed.

Since T max equals the total time available for designation, the track is extended past the crossover point to the last possible impact point in the receding direction. The maximum range of the missile (RMM) is known. RMM is drawn between own ship and the track so as to intersect the track line at maximum impact point. This is done in both receding and approaching directions of the target. Two equal triangles with two known sides (RMM and RSM) are formed. The distance along the track between the CPA and either impact point is equal to $\sqrt{R^2_{MM} - R^2_{SM}}$. The time required by the target to travel this distance is equal to the distance divided by target speed V_H .

It would appear we have solved the T max problem since an addition of $\frac{Y_R \cos E}{V_H}$ and $\frac{\sqrt{R^2_{MM} - R^2_{SM}}}{V_H}$ would provide the total time for

target travel from its present position to the last possible impact point. But time-consuming actions from the instant of designation to the instant of missile interception must be taken into account.

The time-consuming actions between designation and firing are lumped into one correction

called delay time. This correction includes such items as director acquisition time, computer solution time, launcher synchronizing time, target evaluation, and missile firing. Delay time is the sum of the average times for these actions. The delay time value used to find $T_{\max}$ can be varied in the system. Since delay time is consumed prior to firing, it affects the last possible designation time and is subtracted from target travel time. The time of flight of the missile to the impact point (T^2) is also consumed prior to target interception, and is subtracted from target travel time. Maximum range is used, and therefore the time of flight is constant. Now we can arrive at $T_{\max}$ and ΔT

$$T_{\max} = \frac{Y_R \cos E}{V_H} + \frac{\sqrt{R^2 MM - R^2 SM}}{V_H} - (T_D + T^2)$$

$$\Delta T = \frac{2\sqrt{R^2 MM - R^2 SM}}{V_H}$$

Since T_D and T^2 are equal for an approaching target and a receding target, they cancel in the ΔT formula. The difference between $T_{\max}$ and ΔT gives $T_{\min}$.

When an extremely high speed target is involved, the formulas for $T_{\max}$ and ΔT are changed. The change is made when the time required for the target to travel to the crossover point in the track is smaller than ΔT . Hence the delay time and time of flight for approaching and receding tracks no longer cancel. Target speed voltage is compared with a voltage representing a critical speed in a comparator. The output of the comparator operates a relay which shifts the data flow in the computer to change the formulas. The formula for ΔT becomes $R^2 MM - R^2 SM + T^2 - RSM \tan \phi = \Delta T$. The angle ϕ equals the lead angle. The formula for $T_{\max}$ becomes

$$\frac{Y_R \cos E}{V_H} - \frac{RSM \tan \phi}{V_H} - T_D = T_{\max}$$

The evaluation computers produce d-c voltages corresponding to the amount of time left, in seconds, during which the target may be engaged and the length of time until a target may last be engaged. These voltages produce time displays in the multipurpose display.

DIRECTOR-CHANNEL SWITCHING

Director-channel switching provides the circuits which interconnect the designation sources with the FCSs. The path of designation data from a selected source, and repeat-back data from the assigned FCS, are controlled by relays and automatic rotary switches. Thus the components and circuits are conventional, but the circuits are large and complex to obtain maximum flexibility. The designation circuits are conventional; the paths vary between installations, and therefore will not be taken up here.

WEAPON ASSIGNMENT CONSOLE

The Weapon Assignment Console (WAC) displays the tactical situation of the missile fire control systems. The console display is covered in chapter 4 of this course. The principles of operation of the circuits in the WAC are similar to the circuits which perform the same function in the TSTC. Therefore details of circuit operation will not be covered.

There are two PPI-scopes in the WAC. Each scope is associated with a missile system and display data from that system. The display consists entirely of symbols. The symbols are generated in the same manner as in the TSTC and the same audio-frequency supply is used. Symbol positioning voltages are supplied from the FCS. All symbol brightening voltages with the exception of own-ship heading and clearance line voltages are completed through a relay controlled by an on-target signal from the FCS. Hence when a FCS is not tracking, its symbols are not displayed in the WAC.

LAUNCHER-DIRECTOR SWITCHING

The launcher-director switching system interconnects circuits which assign a launcher to a FCS, cancel launcher assignments, monitor certain FCS and launcher data, and initiate loading and firing of missiles. The switching system can be broken down into four circuit groups. Launcher signaling (to and from the console) circuits relay the launcher system's status. The salvo select and firing circuits generate signals that result in the selection and the firing of missiles. The launcher assignment circuits control the switches, as required, for making or canceling launcher assignments. The launcher time delay circuit permits the manual

insertion of a time delay into the fire control computer. There are two identical launcher channels, each associated with a display in the WAC. Some of the switching circuit components are designated R for right scope or L for left scope. The missile launcher rails are denoted A and B. Components designated A or B are associated with switching functions for the respective missile rails.

The switching circuits are complex but conventional. The signal and data circuits vary according to the particular installation and system. Therefore we will not cover the exact data transmitted, or the circuits.

TARGET DESIGNATION SYSTEM

The Target Designation System, TDS, that we will consider here is installed on ships with conventional gun batteries. The operation of the system was covered in chapter 4 of this course. The major units are: a designation indicator unit with its associated video generator, and a coordinate converter. The functions of the units are similar to their counter units in the WDE. Hence the circuits and components in the units are similar to their counterpart in the WDE. Therefore our discussion of the TDS circuits will take the form of an overview.

DESIGNATION INDICATOR UNIT

The Designation Indicator Unit has a conventional PPI-scope. It displays radar video, range markers, movable designation hooks, and feedback hooks from the FCS. The search radar supplies the indicator with video signals, sweep signals, and timing triggers at its PRR through an automatic switchboard. The radar video time shares the CRT with the designation hooks and the feedback hooks.

Timing Circuits

The passage of time in the indicator is measured by multivibrators located in the video generator. There are six major timing gate circuits or multivibrators which operate in the following sequence: sweep length, reset gate, hook position gate, dot gate, delay gate, and hook painting gate. The sweep length gate is opened by the timing trigger from the radar. Each remaining gate is opened by the trailing edge of its predecessor. The length of time

the gate is open is determined by circuit components.

The SWEEP-LENGTH GATE timing period is determined by the maximum range of the presentation. The range scale of the presentation can be shifted. While this gate is opened, radar video is displayed and radar sweep circuits are applied to the CRT deflection system.

The RESET GATE, when operated, blocks all signals to the presentation circuits to allow time for the circuits to return to their neutral condition.

The HOOK POSITION GATE opens the circuit between the CRT and the hook position signal from the coordinate converter.

The DOT GATE actuates the delay gate before the hook painting gate.

The DELAY GATE operates and delays the video signal to the CRT until the symbol oscillator output reaches its full magnitude.

The HOOK PAINTING GATE opens the circuit from the hook symbol video circuit to the CRT. When this gate closes, the display cycle has been completed. The scope is now ready for the radar timing trigger to start the next cycle.

Sweep Circuits

The CRT sweep deflection is electromagnetic. This means that it uses current flow through deflection coils, rather than voltages applied to deflection plates. The PPI requires the currents in the X and Y coordinates. Data entering and leaving the system are in polar coordinates; hence coordinate conversion is necessary. This is accomplished in the coordinate converter, which also rotates the coordinate systems between relative and true axes. The display is true, while the transmitted data is normally relative. Coordinate conversion and axes rotation are explained in chapter 3 of this course. The PPI has a 2-coordinate display; target height is not presented in the scope.

The radar range sweep position is controlled by the antenna bearing signal which is converted to the X and Y axes by a resolver circuit. The principles of this type of circuit were explained earlier. The feedback hooks are positioned by bearing and range signals from the FCSs. The polar coordinate signals from the FCS are converted to rectangular coordinates in the converter. The movable designation hooks are positioned by the console joysticks. The joystick has two balanced bridge

circuits, one aligned with the X-axis and the other with the Y-axis. Each bridge circuit contains two potentiometers whose wiper arm is moved by the joystick. When the stick is moved from its neutral position it changes the voltage outputs of the potentiometers and moves the hook.

The hook sweep voltages are present in the sweep generator, and are applied to a ring counter circuit. When the hook gates are opened, the ring counter shifts to the next set of tubes. Thus the hooks are displayed in a fixed sequence.

The hook symbol is generated in a manner similar to the symbols in the WDE. The sym-

bol voltages from a local oscillator are superimposed on the sweep positioning signals.

OVERHEAD CONTROL UNIT

The overhead control unit provides switching to interconnect the designation channels with the FCSs. In systems with the overhead unit installed, the designation channels are not rigidly assigned to a FCS. A supervisor or evaluator can control the designation source for each FCS. A manual elevation input is provided for each channel. When target elevation is known or can be estimated, a designated elevation is transmitted. The circuits in the overhead unit are conventional.

CHAPTER 13

TEST EQUIPMENT

INTRODUCTION

The proper operation of almost any piece of fire control equipment requires constant maintenance, either preventive or corrective. To perform this maintenance effectively it is necessary to use and rely on various types of test equipment.

Test equipment of various types, much too numerous to be listed here, must be at the command of the fire control technician. Proper use of this equipment and its capabilities must be known. With each piece of test equipment there is usually an instruction book giving the information on operation and use of the equipment.

In this chapter we will consider some of the test equipment available to the fire control technician.

DUMMY DIRECTOR AND ERROR RECORDER

Before 1938, the transmission and followup systems of guns and directors were tested only for alinement with all the units of the system at rest. But the director and guns are always in motion when following a moving target, and it is important that they be in alinement not only when stationary but when moving in response to a dynamic signal as well. Thus it became necessary to determine the accuracy with which a director or gun responds to a continually changing signal, such as generated bearing or gun orders. The dummy director and error recorder were developed for this purpose; they provide a means for transmitting an automatic signal to a gun or director and simultaneously measuring the amount that the gun or director lags the signal. These tests are called dynamic accuracy tests.

The first dummy directors and error recorders were issued only to naval shipyards and repair ships, but the newer models are

standard equipment in the plotting rooms of most large combatant ships.

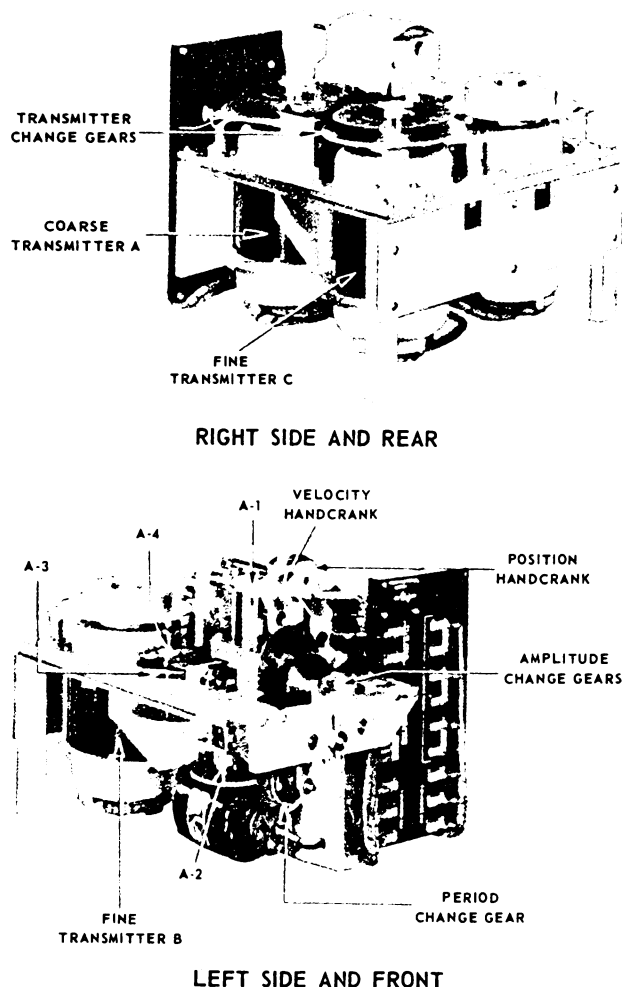
The dummy director introduces angular motion electrically into the system under test—either constant velocity motion or simple harmonic motion. The error recorder makes a record of the test in the form of a time-displacement curve. The curve indicates the difference between the signal to the mount and mount response.

To test a director, gun, or turret in remote control, electrical signals (corresponding to either a constant velocity or a simple harmonic motion of the mount) are transmitted from the dummy director to the remote control equipment at the mount or director and to the error recorder. The error recorder also receives a signal corresponding to response from the gun or director under test. As the mount moves in response to the changing signal, the error recorder makes a permanent record of the instantaneous difference between mount order and mount position. The magnitudes of the errors in mount position are determined by measuring (from a reference line) the displacement of the curve produced by the error recorder. Transparent scales are supplied with each recorder for this purpose.

The curves obtained from a dynamic accuracy test should be compared with the curves taken when the equipment was accepted by the Bureau of Weapons. If the curves from the periodic tests show rough followup action or a response lag in excess of that specified for the particular mount, the power drive should be checked for malfunctioning. The controls should be adjusted to bring the dynamic accuracy tests within allowable limits of error.

DUMMY DIRECTOR MK 1 MOD 3

Dummy Director Mk 1 Mod 3, shown removed from its case in figure 13-1, is designed



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Figure 13-1. —Dummy Director Mk 1
Mod 3 removed from its case.

to transmit electrical orders simultaneously to three synchro circuits. The output of the synchros—depending on the gear ratios selected—is as follows:

1. The output of coarse transmitter A is proportional to 720°, 360°, 240°, 180°, or 100 seconds fuze-setting time per revolution.
2. The output of fine transmitter C is proportional to 10°, 5°, 2.5°, or 2 seconds fuze-setting time per revolution.
3. The output of fine transmitter B is always proportional to 10° per revolution.

Figure 13-2 is a schematic diagram of the dummy director. Refer to it throughout the following discussion. The three principal parts

are the power motor, component integrator, and synchro transmission system.

The power motor is a constant velocity motor of the synchronous type. The synchro transmitters are size 7G. The component integrator is a standard ball type integrator. Notice that only the output of the cosine shaft of the integrator is used.

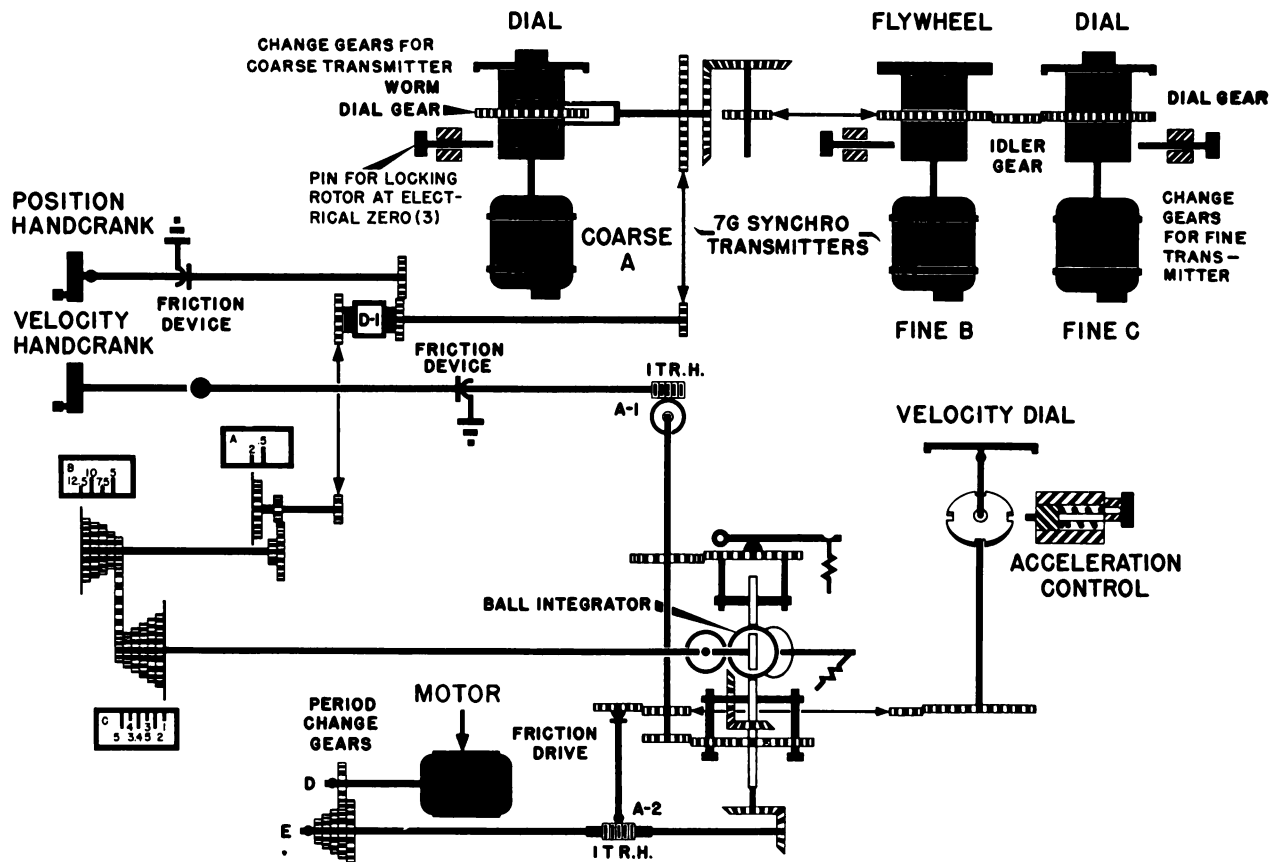
The motor turns both inputs to the component integrator. If the axis of the driving roller is held at a fixed angle, while the driving roller is rotated, the velocity of the output is constant. If both the driving roller and the axis of the driving roller are turned at a constant speed, the velocity of the output varies sinusoidally.

The output shaft of the integrator drives through two sets of change gears and D-1 to the rotors of the synchro transmitters. (The voltages generated in the stator windings of these synchro units are the outputs of the dummy director.) The rotors of the synchro transmitters can also be turned by the handcrank input to D-1. A friction device on the shaft prevents the output of the integrator from backing out through the handcrank.

When a sinusoidal signal is required, worm gear A-1 is disengaged and the detent of the acceleration control is moved clear of the detent plate. The period of the signal is determined by installing a gear of the proper size on the power motor shaft. The size of the gear governs the speed of rotation of the axis of the integrator driving roller about the axis of the integrator output shaft. Gears for 4.44-, 9-, 12-, 18.8-, 31.2-, and 60-second periods are provided with each dummy director. The amplitude of the period is controlled by the change gears between the integrator and the synchros. The signal oscillates about a reference point selected by the handcrank.

When a signal of constant velocity is required, the axis of the driving roller is held at a fixed angle with respect to the axis of the output roller by either engaging gear mesh A-1, or by engaging the detent of the acceleration control. When prolonged tests at constant velocity are conducted, excessive wear of the friction drive can be avoided by slipping clamp A-2.

The signal velocity is adjustable between zero and maximum (determined by the period and amplitude change gears) by engaging A-1 and turning the velocity handcrank. The velocity of the output can be checked by timing the rotation of the fine dial.



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Figure 13-2.—Dummy Director Mk 1 Mode 3 gearing diagram.

If the detent lock is used instead of A-1, the signal velocity can be varied only by the period and amplitude change gears, because the detent locks the axis of the driving roller at either zero or maximum velocity position.

The axis of the driving roller should always be set for zero velocity before starting the power motor. Thus excessive acceleration of the signal is avoided.

The gear ratio between coarse transmitter A and fine transmitter B may be altered by changing both the gear mounted on the rotor of the coarse transmitter and the worm that drives it. Similarly, the gear ratio between fine transmitter C and fine transmitter B may be altered by changing the gear mounted on the rotor of fine transmitter C and the idler that drives it.

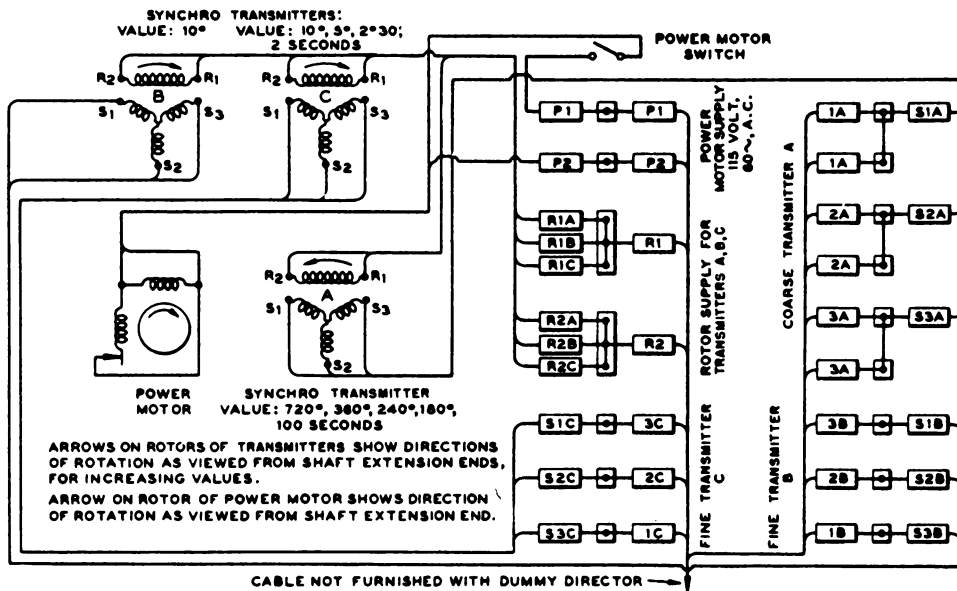
Figure 13-3 is a schematic wiring diagram of Dummy Director Mk 1 Mod 3.

DUMMY DIRECTOR MK 3 MODS 0 AND 1

Dummy Director Mk 3 all Mods is an improvement over the Mk 1 Mod 3. It consists of three synchro transmitters driven by a control mechanism in either simple harmonic (SHM) or constant velocity motion (CVM), at variable amplitudes.

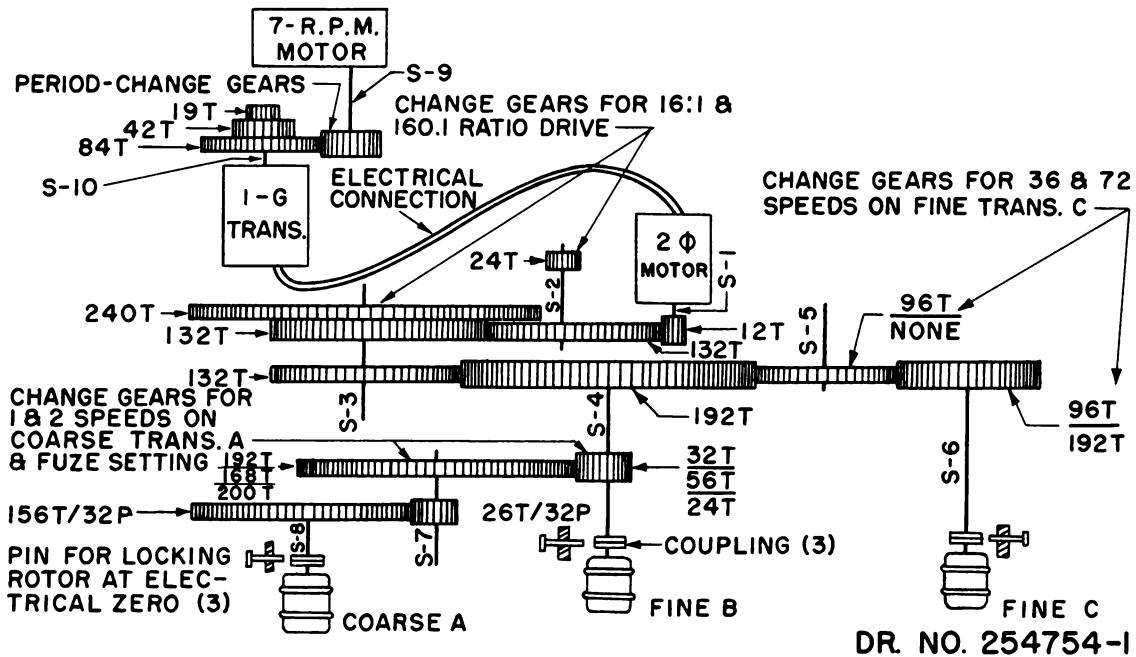
Synchros A and C (type 6G) transmit electrical angular motion to the equipment under test, while synchro B (type 5G) supplies a signal to the differential of the error recorder (fig. 13-4).

A motor of 7 rpm turns synchro transmitter 1G through the change gears on shafts 9 and 10. The speed of rotation of the 1G controls the period of SHM. Periods of 2, 4, 5, 6.9, 9, 11.8, 13.1, 14.7, 18.1, 23.6, and 29.4 seconds can be obtained by substituting the proper gears on shafts 9 and 10 (fig. 13-4).



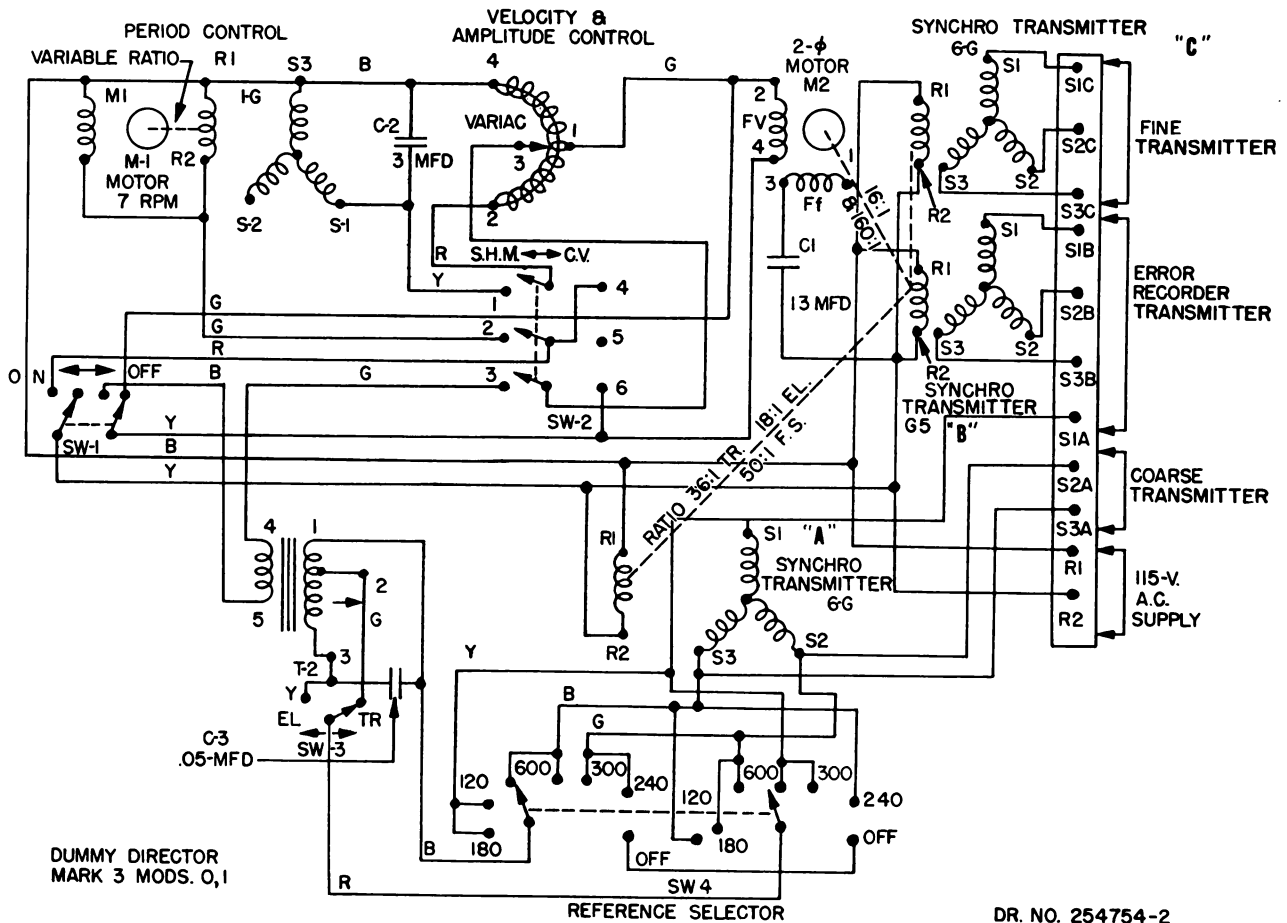
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Figure 13-3.—Dummy Director Mk 1 Mod 3 wiring diagram.



92.118

Figure 13-4.—Dummy Director Mk 3 all Mods gearing diagram.



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Figure 13-5.—Schematic wiring diagram of Dummy Director Mk 3 Mods O and 1.

The single phase armature winding (R1 and R2 of the 1G) is energized through the ON-OFF toggle switch SW-1 (fig. 13-5). Only one phase of the three-phase output of the 1G is used. This voltage, whose amplitude and polarity vary as the sine of the angular displacement of the rotor, is impressed on terminals 2 and 4 of the variac whenever SW-2 is in the SHM position. Condenser C-2 is inserted to counteract the lag in current caused by the high inductance of the field winding of the 1G.

The contact arm of the variac is turned by the amplitude control knob mounted on the armature shaft. The position of the arm is read on a dial mounted beneath the control knob. The dial has two scales. The top scale (fig. 13-8) is calibrated in degrees of constant velocity per second, while the right-hand scale is graduated for the amplitude of the SHM.

The output of the variac, between the fixed center contact 1 and the movable contact 3, is impressed across the variable field winding Fv of motor M-2, in series with a reference voltage from the secondary of transformer T-2. The primary of T-2 (fig. 13-5) is energized from the stator winding of synchro generator A through SW-3 and SW-4. Condenser C-3 serves the same purpose as C-2.

Reference selector SW-4 selects the phase and polarity of the output of synchro A. Thus six reference points—each 60° apart—about the reference circle are available.

The current through the fixed field winding Ff of M-2 leads the applied voltage by 90° as the result of the 13 mfd. condenser C-1 in series with the winding.

The output of M-2 (Fig. 13-4) reduced by the 1:16 gear ratio on shafts 1, 2, 3, 4, 5, and

6—turns the rotors of fine synchros B and C. Shaft 4 also turns the rotor of A through shafts 7 and 8. The ratio between B and A is 18:1 for an elevation signal and 36:1 for a train signal.

A removal flywheel on shaft S-1 smooths the operation and eliminates sudden accelerations of M-2.

When SW-2 is in the CV position (fig. 13-5), the output of synchro 1G and transformer T-2 are replaced by the 115 volt supply at terminals 2 and 4 of the variac. By adjusting the variac, the speed of M-2 can be regulated in either direction. The velocity of the motor is read in degrees per second on the CV portion of the dial.

Theory of Operation of the Mk 3 all Mods

Under constant load the speed and direction of rotation of any two-phase squirrel-cage induction motor are controlled by the magnitude and polarity of the signal impressed on one of the field windings. The Dummy Director Mk 3 all Mods used these characteristics of an induction motor (M-2) to generate SHM.

As the rotor of synchro 1G turns, the peak value of its 60-cycle output (between taps S-1 and S-3) changes sinusoidally. The polarity of the a-c output, with respect to the reference voltage, reverses with each one-half revolution of the 1G.

This a-c voltage, whose value is changing sinusoidally, is impressed on the variable field winding Fv. As a result the speed of M-2 varies sinusoidally from zero to maximum and back to zero during the first one-half revolution of the 1G. During the next one-half revolution of the 1G the polarity of its output reverses. Consequently M-2 reverses and its speed varies sinusoidally in the opposite direction. Every sinusoidal motion has a reference or zero line. In the Dummy Director Mk 1 the reference line was selected by a handcrank (fig. 13-2). In the Mk 3, Mods 0 and 1, the reference point is changed by selecting any one of the 6-phase outputs of synchro A, through SW-4, and T-2 (fig. 13-5).

Motor M-2 drives in response to the sum of the voltages from the 1G and T-2. To understand the action of the motor, let's first examine its action when the variac is on zero.

Synchro A (through the step-down transformer T-2) is connected to Fv so as to oppose rotation of the motor from the rest point, as in figure 13-6A. If the motor drifts clockwise,

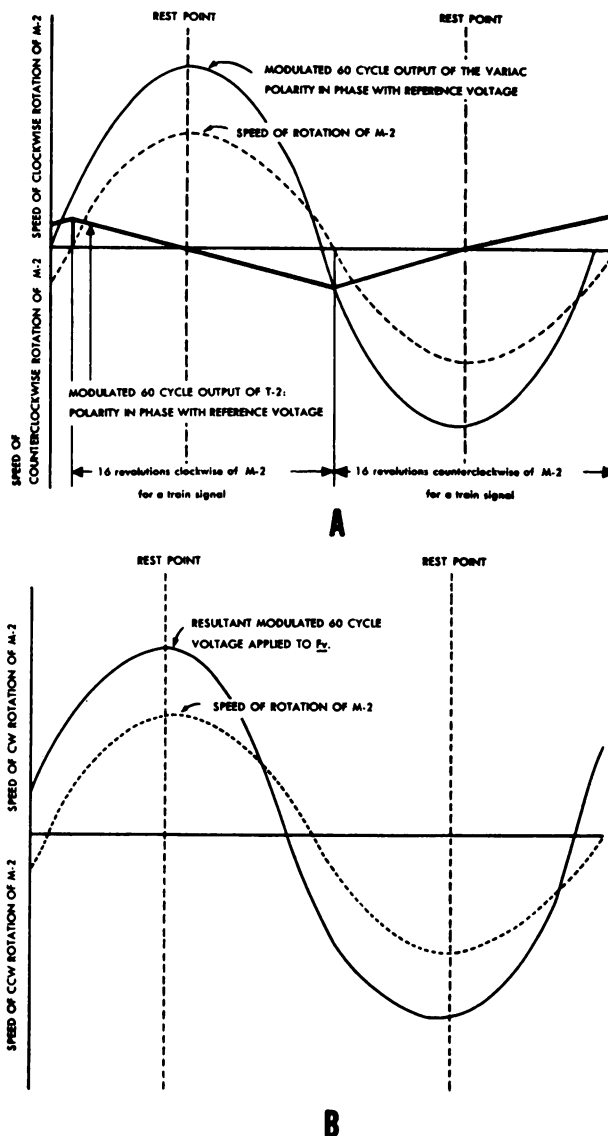


Figure 13-6.—Voltages applied to M-2.

the output of T-2 increases in the direction required to turn the motor counterclockwise. Consequently the motor remains at rest when the variac is on zero.

Since there are six phase outputs of synchro A, M-2 has six rest points 60° apart around the training circle. You can easily verify this. If you set the variac on zero and turn the reference selector switch, the motor will turn synchro A 60° each time.

Let's consider the action of M-2 when the variac is set for SHM—say a ten-degree roll. (M-2 turns synchro A through a gear reduction of 288.1 for an elevation test, and 576.1 when a train signal is desired. Bear in mind also that the rest point of M-2 corresponds to the point of its maximum speed when a sinusoidal signal is impressed on Fv.)

The output of the 1G, during its first one-half revolution, causes M-2 to rotate clockwise. When M-2 crosses the rest point it is turning at maximum velocity. (See fig. 13-6A.) Its speed is almost in time phase with the signal voltage from the 1G. The output of T-2 increases and subtracts from the 1G signal.

This opposing voltage (whose peak is approximately equal to the peak output of the variac) acts to decelerate M-2, since it is in phase opposition to the 1G signal.

When M-2 has turned the full amount CW, synchro A is offset from zero by 10° (for a 10° roll) and is producing its maximum opposing signal:

$$\frac{T-2 \text{ (primary)}}{T-2 \text{ (secondary)}} \times (\text{Max. phase output of A}) \times \cos 10^\circ.$$

Then the signal from the 1G reverses polarity. But the motor, because of the inertia of the system, overrides the point of reversal. Now the T-2 signal is in phase with the 1G signal, and the two voltages add to provide the high torque needed to reverse M-2. Moreover T-2 and 1G remain in phase until the motor again crosses the rest point, thus helping to accelerate the motor.

The addition of these two voltages results in the wave shape of figure 13-6B. When the motor is accelerating, the signal voltage is slightly higher than that of a pure sine wave—the reverse is true when the motor is decelerating.

Referring again to figure 13-5, notice that SW-3 has two positions—one for train, and one for elevation. When SW-3 is on EL, T-2 steps down the voltage output of synchro A by 18:1. The step-down ratio is only 9:1, however, for a train signal.

This arrangement is logical. The gearing between M-2 and synchro A is 288:1 for an elevation test, and 576:1 for a train test. Thus, for a train test (of the same period and amplitude as an elevation test), M-2 must turn twice as many revolutions in the same time to produce the same displacement of synchro A. Therefore the opposing signal from T-2 is halved.

Dummy Director Mk 3 Mod 2

Figure 13-7 is a schematic wiring diagram of Dummy Director Mk 3 Mod 2. The only difference between the Mod 2 and the Mods 0 and 1 is that selector SW-4 has been replaced by a synchro differential transmitter (type 1DG).

The 1DG is a distinct improvement over the reference selector switch. The reference line of the SHM can be trained (in an infinite number of steps) through 360° , instead of through only the six steps—each 60° apart—available in the Mods 0 and 1.

The dial group of Dummy Director Mk 3 Mod 2 is shown in figure 13-8.

ERROR RECORDER MK 1 MOD 3

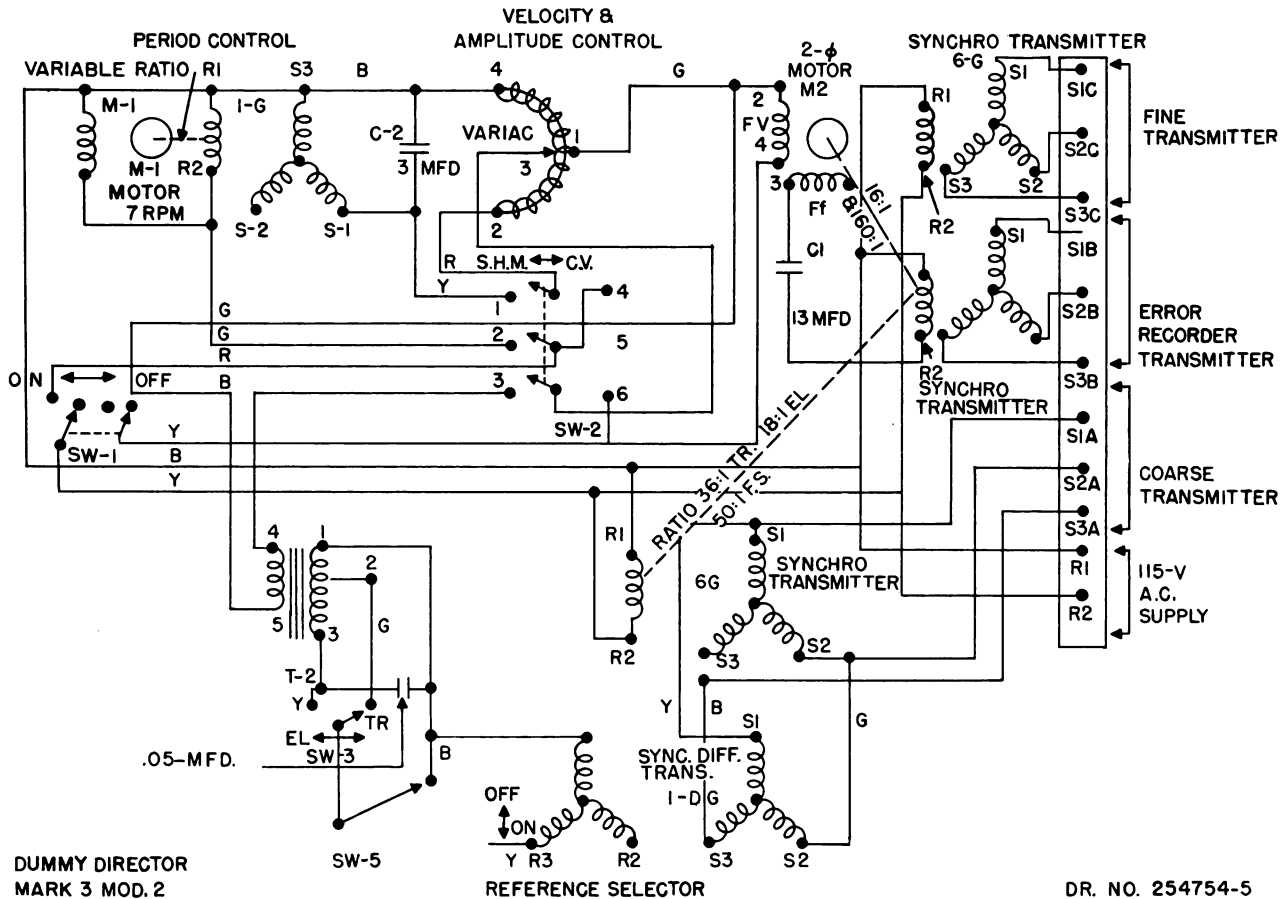
The Error Recorder Mk 1 Mod 3, shown removed from its case in figure 13-9, can be used with either the Dummy Director Mk 1 or Mk 3. It records the dynamic error of a mount when following the automatic signal generated by the dummy director.

The error recorder consists of a paper drive and a recording mechanism. The paper drive is a metallic drum turned at 2 rpm by a synchronous receiver through a speed reducer. The paper is held against the drum by two springs and two rollers, and is driven past the recorder at a constant speed proportional to time.

The recorder element consists of an electrode mounted on the shaft of a synchro differential transmitter (type 5DG). The electrode is energized by a spark coil (fig. 13-10), and the metallic drum is grounded. When a voltage is impressed on the spark coil, sparks pass between the electrode and the metallic drum, marking the paper. Simultaneously a second stationary electrode and spark coil make a straight reference line at the edge of the paper.

The rotor of the 5DG, turning in response to the difference between the electrical signals impressed on its rotor and stator, causes the electrode to swing in an arc across the paper. At the same time, the sparks from the electrode form a permanent record of the displacement of the rotor.

The error between mount position and the signal to the mount, when the mount is following a SHM signal, is in the form of a sine wave. Figure 13-11 is a sample error curve from a Mk 37 Director with Arma controls. The error in response is measured as explained in the figure.



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Figure 13-7.—Schematic wiring diagram Dummy Director Mk 3 Mod 2.

When the error recorder is used on a mount where the synchro transmission system has a value of 10° for each revolution of the fine synchro, the curve can be read in seconds of time and minutes of error as shown. If any other speed of transmission is used, however, the transparent scales must be recalibrated.

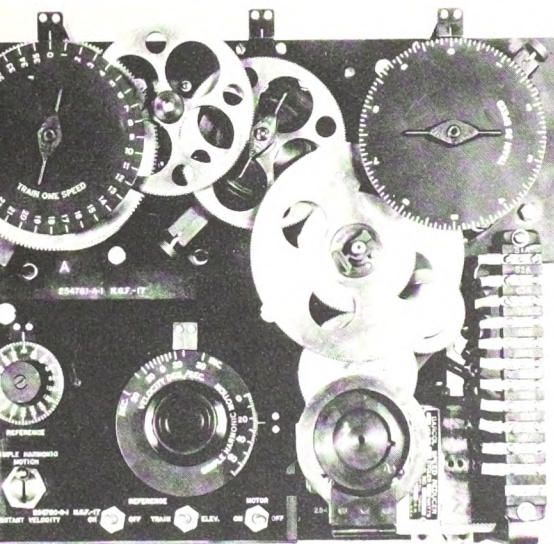
DYNAMIC TESTER MK 31 MOD 1

One of the typical dynamic testers used to check the dynamic performance of the computers in guided missile fire control systems is the Dynamic Tester Mk 31 Mod 1. The tester is designed to provide an accurate and rapid means of checking the computer on a go or no-go basis using a series of error indicator lamps. If these lamps indicate faulty computer operation, the test must be rerun using the

Error Recorder Mk 9 Mod 0 to record the test graphically. These tests determine the computer overall dynamic performance by concurrently checking six computed output orders. This facilitates routine checks of the computer and tests performed after installation, repair, or overhaul.

The tester (fig. 13-12) is a small, compact, self-contained unit designed for bulkhead mounting with all controls located at the front of the instrument.

The overall operation of the tester is illustrated in the simplified functional diagram, figure 13-13. The tester continuously generates problem data for a simulated target and own ship's motion, which are transmitted to the computer. These data are used by the computer to calculate solutions for launcher and missile orders for the test problem. Simultaneously, the tester generates precalculated solutions for



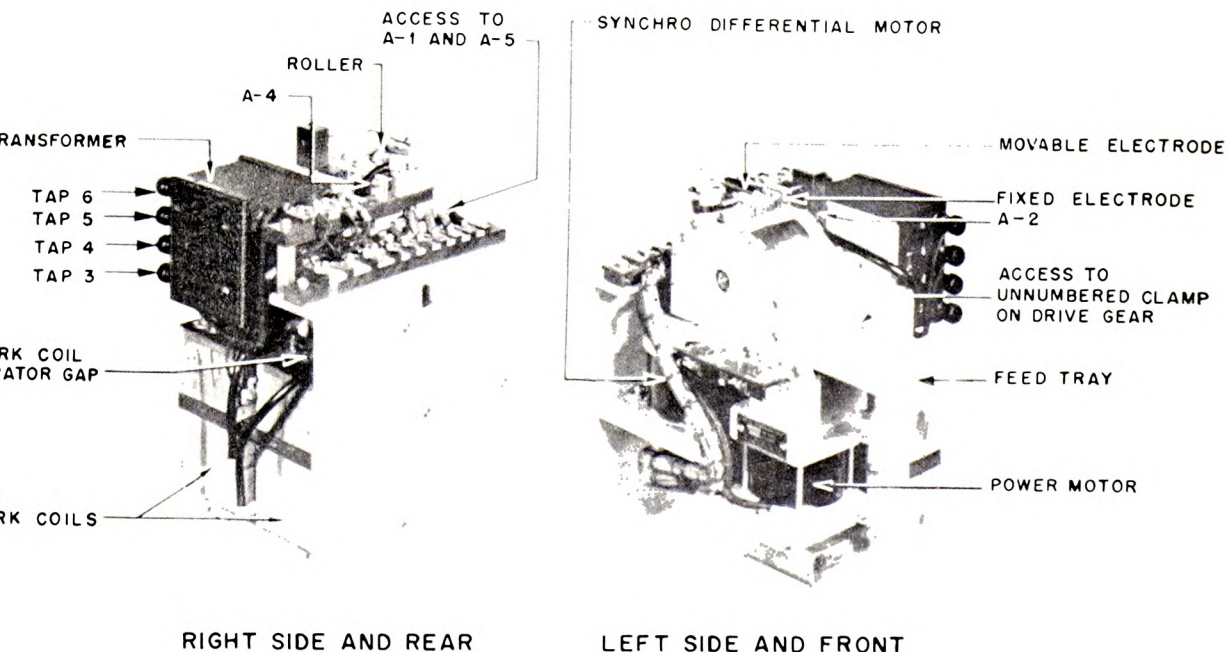
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Figure 13-8. —The dial group of Dummy Director Mk 3 Mod 2.

order solved by the computer and continuously compares the computer solutions with the calculated solutions. The differences, which are the outputs from comparator circuitry in the

tester, are the respective dynamic errors of each order. These error signals are transmitted either to individual error sensors in the instrument or to external error recorders such as the Error Recorder Mk 9 Mod 0. When the error signal exceeds a predetermined value for a particular order, and error indicator display is selected by the selector switch, the associated sensor causes an indicator to light. The error recorder presents a continuous tape display of the errors that occur during the problem run.

The simulated problem is usually set for a definite period of time of target flight (usually about a minute), either for increasing or decreasing bearing rates, as preselected by appropriate tester switching. The original straight-line course of the target is deliberately altered to result in a series of parallel straight-line paths by introducing three step-changes at predetermined points during the problem run. Each step-change provides a transition interval during which changes in elevation, bearing, and range rates are abruptly altered to check the stability and resynchronization time of the computer servoloops. During these transition intervals, the light circuitry is deenergized to prevent the display of meaningless errors.



RIGHT SIDE AND REAR

LEFT SIDE AND FRONT

Figure 13-9. —Error recorder Mk 1 Mod 3 removed from case.

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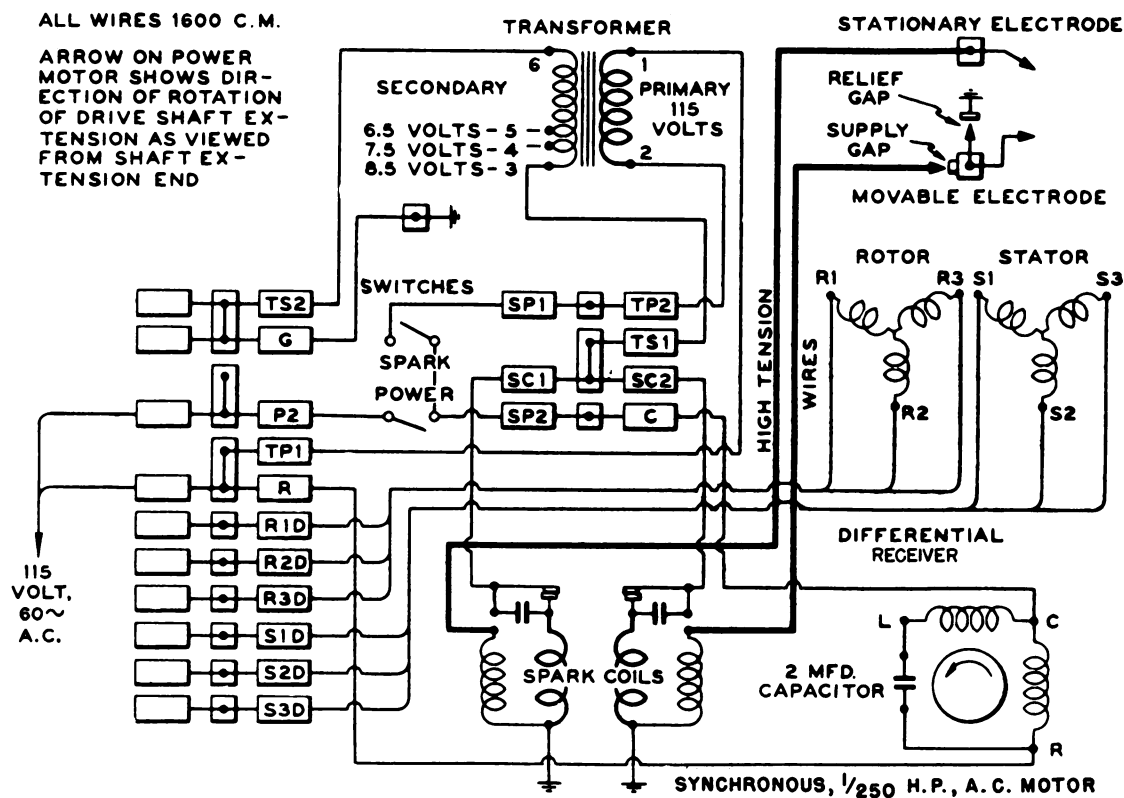


Figure 13-10.—Error recorder Mk 1 Mod 3 wiring diagram.

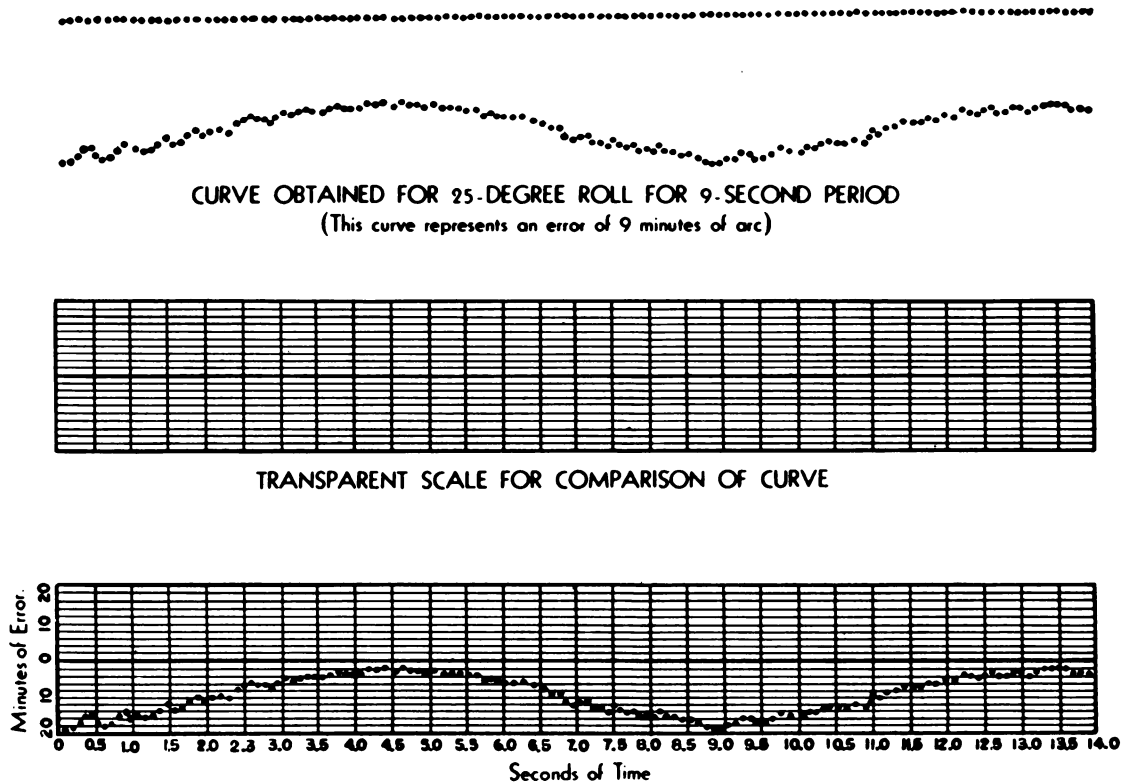
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ERROR RECORDER MK 9 MOD 0

The Error Recorder Mk 9 Mod 0, (fig. 13-14), is a compact six-channel recorder used primarily with a dynamic tester to test guided missile and gun fire control computers and power drives. The unit may be bulkhead or deck mounted aboard ship.

The Error Recorder consists of a cabinet internally divided into three compartments. One compartment houses the power supply; the second compartment contains six Recorder Servoamplifiers. The third compartment houses the Chart Drive and the Pen Motor Assemblies. A door with a glass window covers the chart drive and pen motor assemblies. The front panel of the power supply compartment contains the switches and indicators used for controlling the main power supplies and the chart drive motor. The power supply and regulator provides + 200 v d-c regulated and + 275 v d-c

unregulated for the servoamplifiers. A reference supply unit supplies the reference voltages utilized by the servoamplifiers and pen motor assemblies. The six recorder servoamplifiers are used within the error recorder to power the six pen motors. Each amplifier controls a different writing channel. The chart drive unit is a rectangular housing containing the paper drive and transmission assemblies, the paper supply, and other electrical and mechanical components associated with the writing operation. For descriptive purposes, the chart drive assembly is divided into two sections. The first section contains the writing table, the paper supply shaft, two event marking assemblies, and an electrical subchassis. The writing table is a metal plate easily removed from the unit for replacement of the paper supply roll. A lock fastener secures the plate during operation. The paper supply shaft, mounted behind the writing table, is a metal rod with a flange at



The time from peak to peak is read on the horizontal scale. The error in minutes of arc is read on the vertical scale, and is then divided by 2. Here the reading of 18:2 represents an error of 9 minutes, which is within the maximum allowance error of 10 minutes for a roll of 25 degrees. A similar curve, if obtained for a roll of 20 degrees or less however, would indicate excessive error.

55.311

Figure 13-11.—A sample error curve obtained with a dummy director when checking operation of an Arma-control director in train.

one end. Spring loading of the shaft secures it within the chart drive housing. The two event marking assemblies are mounted on the left and right sides of the chart drive housing. Each consists of a solenoid and armature to which is secured a tracing pen.

The second section contains the paper drive motor, the transmission assembly, the tension roller, the pressure roller release arm, and the paper chute.

The paper drive motor is a 1/25-hp, single-phase, synchronous motor whose shaft is coupled to the transmission assembly. Three solenoids, located in the transmission assembly, are energized in different combinations to produce the various drive speeds.

NOTE: The transmission assembly is a sealed unit which should not be opened in the field.

The six pen motor assemblies are used for writing purposes. The six assemblies are mounted side by side on a diagonal channel secured along the width of the chart drive housing. Each assembly is identical. A typical assembly consists of a Servomotor Tachometer Mk 16 Mod 0, a Synchro Control Transformer Mk 24 Mod 2, a coupling arm and spring assembly, and the thermal writing stylus. Each assembly has a connector which mates with any of the six jacks in the interior of the chart drive unit. The servomotor applies torque to the coupling arm which positions the pen. When the unit is

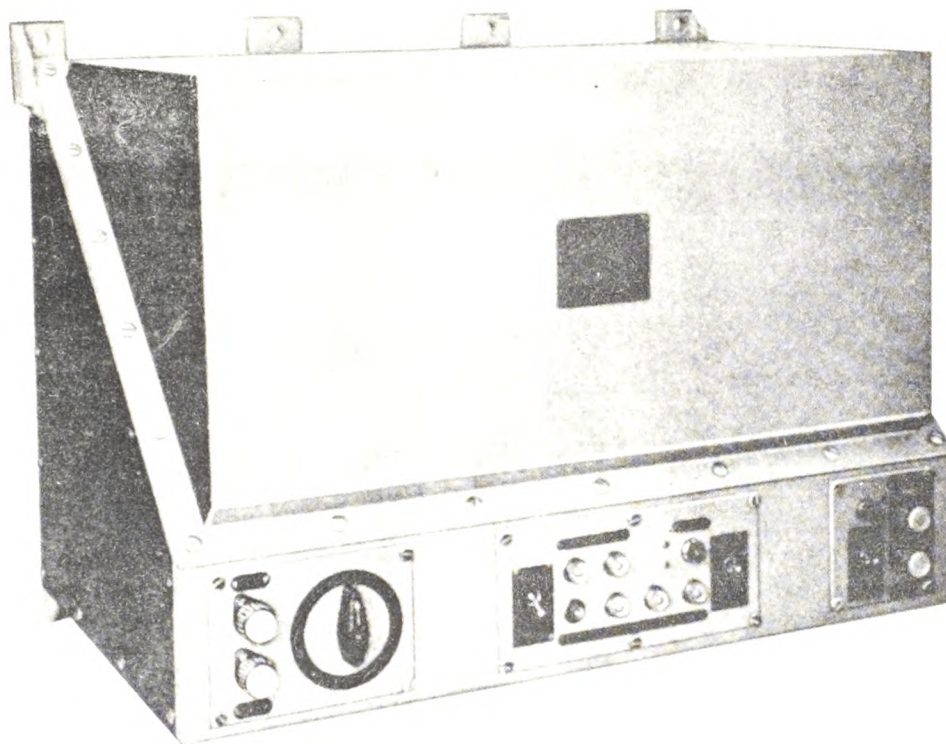


Figure 13-12.—Dynamic tester Mk 31 Mod O.

92.126

deenergized, a leaf spring returns the pen to its approximate zero position. Limit stops prevent excessive pen movement.

The error recorder is supplied with the following accessories: one pair of pliers for removing the writing stylus from the pen mount, one pen pressure gauge used to measure the pen pressure against the paper, and one test cable which enables any of the servoamplifiers to be adjusted or tested when removed from the error recorder housing.

Functional Description

The Error Recorder Mk 9 Mod 0 utilizes servoloops to actuate the tracing pens. A simplified functional diagram of one of the six used within the unit is shown in figure 13-15. The local-remote switches, attenuation, input switching, and choppers are all part of the recorder servoamplifier.

Functionally, the loop performs as follows: The chopping circuits of the amplifier trans-

form all inputs into modulated 400-cycle signals. These are amplified and cause displacement of the servomotor-tachometer shaft, which is mechanically coupled to the pen and the rotor of the synchro control transformer. As the synchro rotor is moved, a feedback voltage is induced in it which is 180 degrees out of phase with the input signal. The servomotor will continue to be displaced until the sum of the input and feedback voltages is zero. When this occurs, the loop is at its null point and the pen movement will cease. With no external signal present, the only input applied to the 400-cycle amplifying circuits is the adjustable zero offset voltage. This can be considered a bias voltage, controlling the no-signal centering point of the servomotor and pen.

Operating Procedure

To operate the error recorder, proceed as follows:

1. Set INPUT selector switch on each amplifier to the desired error signal frequency for

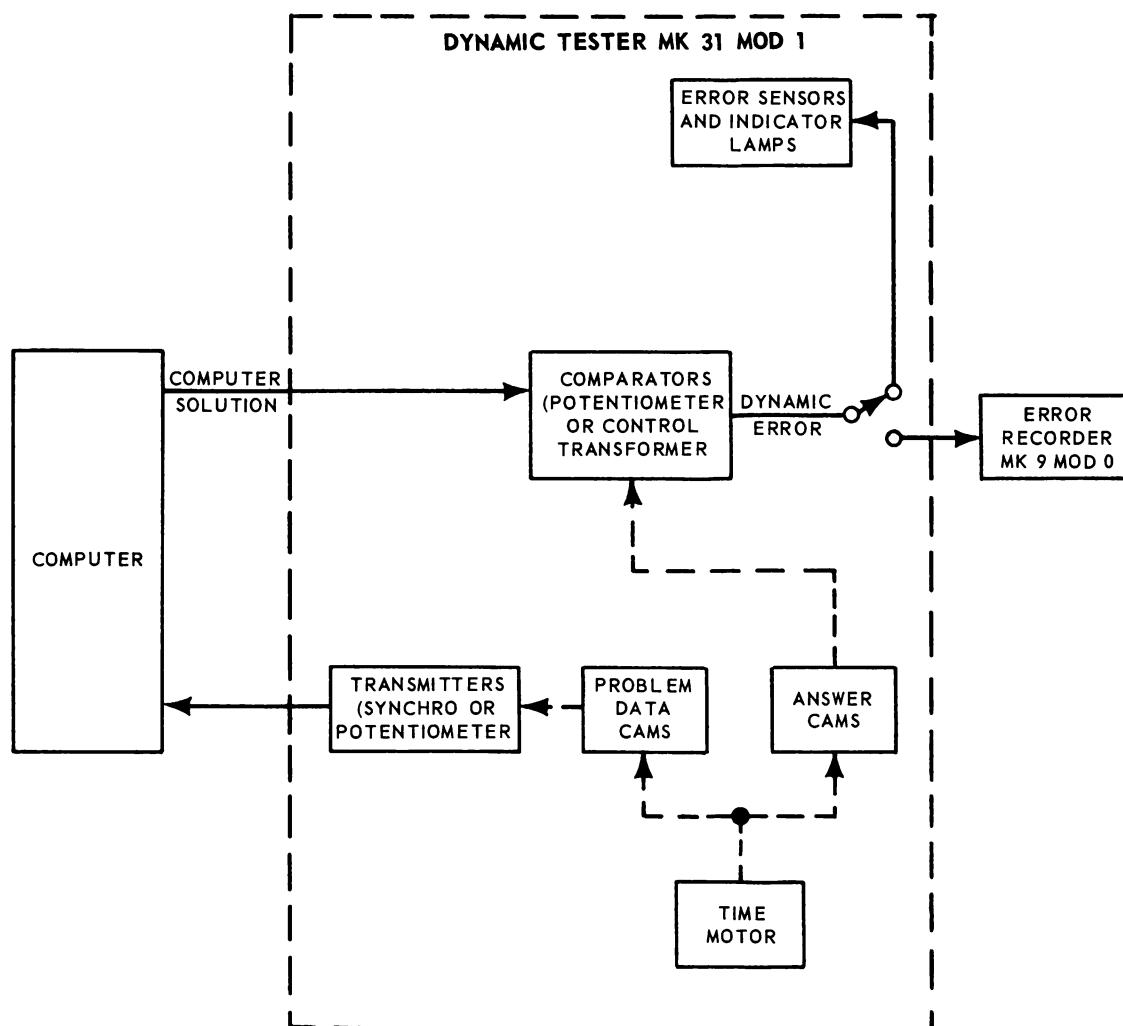


Figure 13-13.—Dynamic tester Mk 31 Mod 1, functional block diagram.

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that channel. Set INPUT toggle switch on each amplifier to LOCAL or REMOTE as required.

2. Set front panel STANDBY and OPERATE switches to ON. The standby indicator will glow immediately. After a delay of about 30 seconds, all servoamplifier ready lamps will light.

3. Set CHART SPEED selector switch to the desired speed.

4. Set CHART DRIVE switch to ON.

Operating Adjustments

PEN CENTERING.—If any pen does not write in the center of its channel, adjust the ZERO

OFFSET potentiometer on the front of the associated amplifier until the trace is centered.

ATTENUATION AND SENSITIVITY ADJUSTMENTS.—The ATTENUATOR selector switch and the SENSITIVITY potentiometer function together to maintain proper trace amplitude. For large input signals the ATTENUATOR selector switch should be switched to the 50 position and the SENSITIVITY potentiometer should be rotated counterclockwise until the trace amplitude is within the recording channel.

NOTE: At large input voltage magnitudes, limiting action within the amplifier clips the

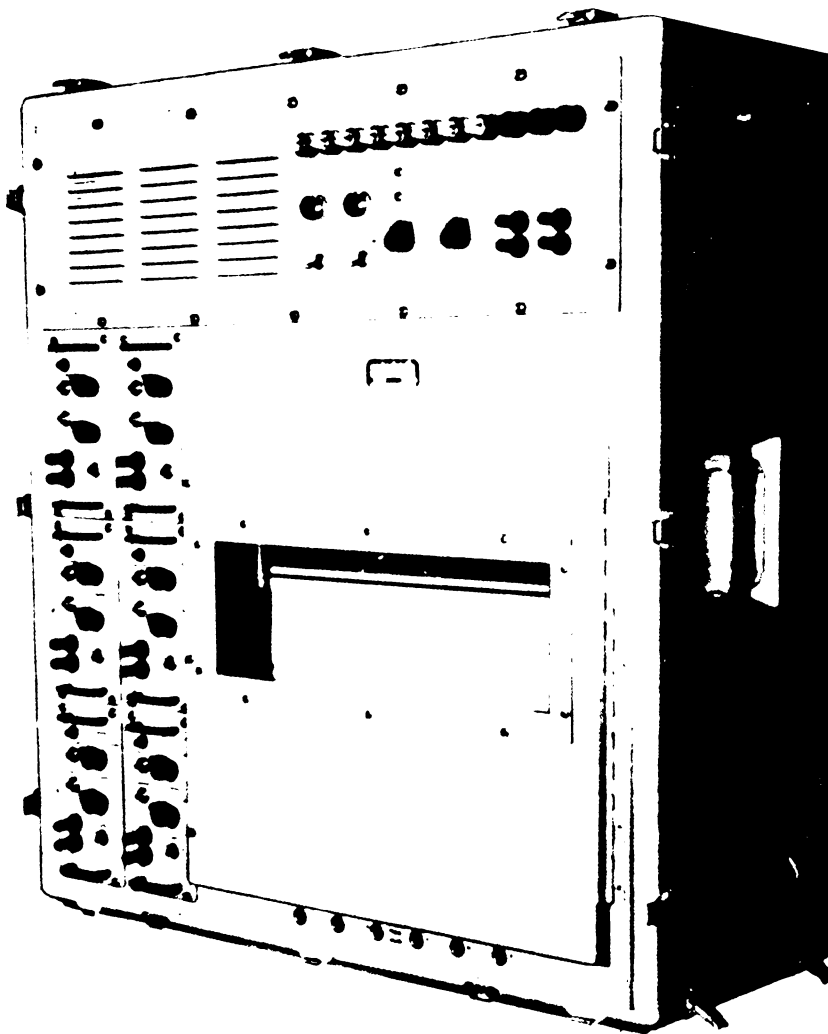


Figure 13-14.—Error recorder Mk 9 Mod O.

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signal unless it is properly attenuated. This causes distortion in the trace.

When very small input signals are applied, the ATTENUATOR selector should be switched to the 1 position and the SENSITIVITY potentiometer should be rotated clockwise until the trace amplitude is clearly defined. Some experimentation may be required for very high or very low input signal magnitudes.

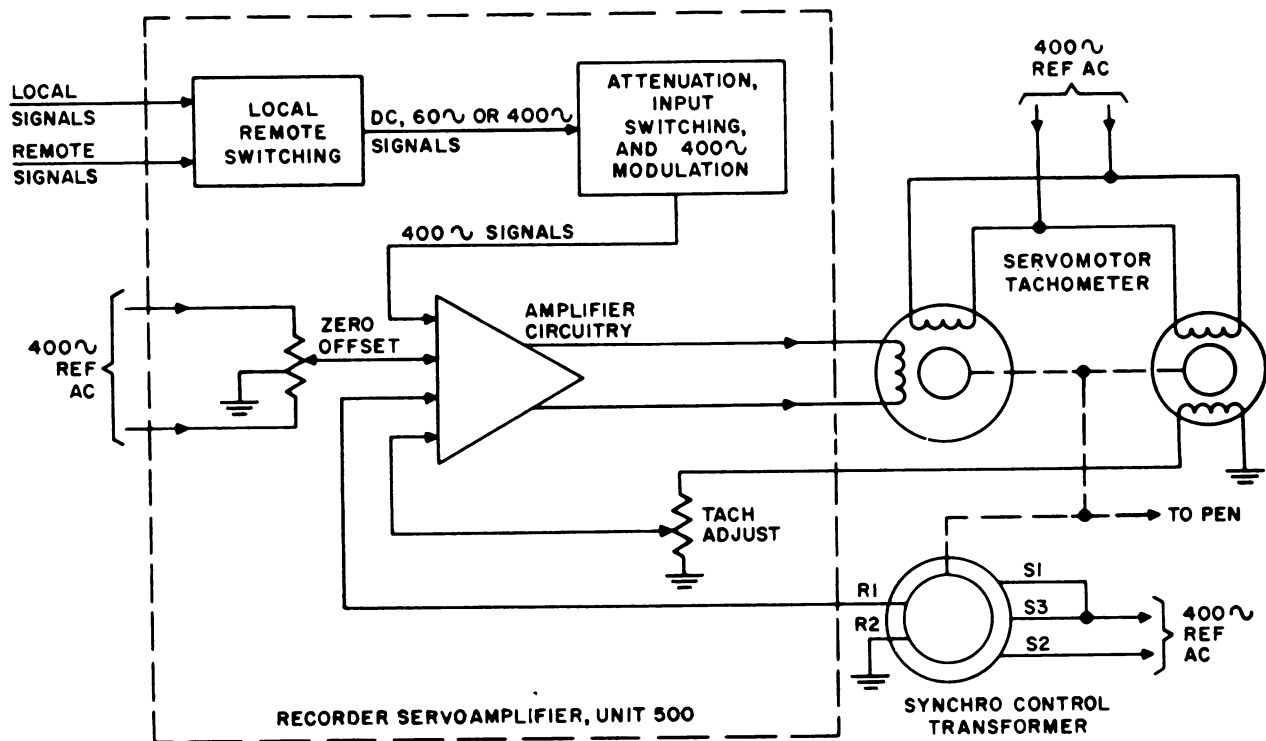
TRACE WIDTH.—Trace width will vary in accordance with the writing velocity of the stylus. At low frequencies (1 to 5 cycles modulation) the trace may be too thick. Rotating the

corresponding TRACE WIDTH potentiometer will thin the trace. At high frequencies (13 to 17 cycles modulation) the trace may be too thin. The TRACE WIDTH potentiometer should be rotated clockwise to thicken the trace.

NOTE: During operation the pens may glow cherry red at high speeds. This is a normal indication.

DYNAMIC TEST ANALYSIS

In computer application the dynamic test is in effect a continuously varying set of A-tests. If excessive static errors exist in the computer,



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Figure 13-15.—Typical pen drive servoloop, simplified functional schematic diagram.

the dynamic test results will be unsatisfactory. Consequently a dynamic test should be performed only after the results of A-test indicate that the static computational errors are within allowable limits.

It is possible too, that excessive static errors exist but are not detected during A-tests. Improper adjustments, for example, may produce results which satisfy A-test problems, but at the same time may cause errors for other static setups. While these errors will not be detected during routine A-tests, they will be revealed during a dynamic test. Excessive dynamic test errors, therefore, should be analyzed first to determine whether the errors are static or dynamic.

One method of determining the nature of excessive dynamic tests errors in a computer is to stop the test run at the point where excessive errors occur and compare the tester and the computer dial readings. If the error persists when the dynamic tester is stopped, static computational refinements are required. If the error drops off, the problem is a dynamic one.

If it is determined that excessive errors are dynamic, servoloop malfunction is indicated. This may be caused by defective servoloop components, improper gain or stability settings or mechanical difficulties such as binding gears, loose clamps, or the like.

The first step in locating the cause of dynamic error is to determine the faulty servoloop. To accomplish this task, a knowledge of the interrelationship of the servoloops in the computer is necessary. Block diagrams are used for this purpose.

With a knowledge of the interrelationship of the servoloops, you as the technician can use the dynamic error curves as an aid in locating the faulty loop.

If the dynamic error exists only in the gun train order (Bdg') curve, for example, it is probable that the Bdg' servoloop is at fault. If dynamic errors exist in several of the output error curves, however, an intermediate servoloop, common to the outputs, is probably at fault.

Locating a faulty intermediate servoloop is often an involved procedure. Critical observation and careful analysis of computer operation during the dynamic test, however, can facilitate this task. For example, sluggish or erratic servoloop action can be detected by rerunning the test through the time cycle in which the excessive errors occur, and observing the operation of the computer dials. (It may be necessary to rerun the test several times before operation of all applicable loops can be observed.) From these observations, and a knowledge of the interrelationship of the servoloops, you as the technician can often determine the faulty loop.

If the faulty loop is not detected by observation and analysis, a systematic signal tracing procedure, using an oscilloscope and a VTVM, must be performed.

Once the faulty servoloop is established, the cause of the trouble must be determined.

Mechanical faults may be detected by manually checking the gearing to see that all mechanical elements rotate freely.

Plug-in units, such as servo controls and servoamplifiers, can be checked by special computer test sets; or the loop may be checked by replacing these units with known good spares.

The input and output voltages of potentiometers, resolvers, servomotors, and synchros should be monitored with an oscilloscope and a VTVM. Check for opens or shorts, noise, wave shape distortion, proper voltage magnitudes, and the like. Check each component through full operational travel.

NOTE: Such malfunctions as intermittent contacts in potentiometers, noisy resolvers or synchro brushes, and the like, will appear as spikes or oscillations in portions of the dynamic test error curves.

Proper gain and stability potentiometer settings and procedures for obtaining them are given in the system OPs. Generally low gain or overstabilization will result in sluggish servoloop operation. Too much gain or understabilization will result in servoloop oscillation.

SYNCHROSCOPE

The synchroscope (cathode-ray type) is an oscilloscope having a fast sweep triggered by a synchronizing signal. The synchroscope considered in this discussion is that of the AN/USM-32. This unit was chosen since its cir-

cuits represent, to a great extent, those common to most of the present day synchrosopes.

The oscilloscope of the AN/USM-32 (fig. 13-16) is a general purpose maintenance instrument, which presents electrical waveforms on the face of a three-inch cathode-ray tube. Signals to be analyzed are normally connected to the vertical signal terminal, from which they pass through built-in amplifiers. Through the use of these amplifiers, a signal as low as 0.28 volt peak-to-peak (0.1 volt rms) will produce an inch of deflection on the oscilloscope cathode-ray screen. The vertical direct terminal provides for direct signal connection to the cathode-ray tube deflection plates, in which case 43 to 52 peak-to-peak volts will produce one inch of deflection.

BLOCK DIAGRAM

The synchroscope of the AN/USM-32 can be considered as consisting of six major sections. These are the vertical deflection system, the horizontal deflection system, the amplitude calibrator, the time calibration circuit, the trigger generator, and the power supply. The block diagram of figure 13-17 shows how the circuits are related in the oscilloscope.

Input signals from the vertical signal terminal are first applied to the input attenuator. The position of the attenuator is controlled by the volts-per-inch control (fig. 13-16), which indicates the amount of voltage required for one inch of deflection. The signal voltage attenuator and vertical gain control permit the application of as high as 600 v d-c to the vertical signal terminal without producing off-screen deflection. The input stage is connected as a cathode follower to present a high impedance to the circuit under test.

Provision is made for delaying the signal through the vertical amplifiers. This is done to allow signals with a fast rise time to be observed on the sweep trace.

The vertical direct terminal provides for direct signal connection to the cathode-ray tube deflection plates. When this connection is used, 43 to 52 peak-to-peak volts will produce one-inch deflection.

A driven-type sweep circuit is employed in the oscilloscope, which can be triggered by the amplified input signal, an externally applied sync signal, an internally available trigger, or the line frequency signal. The choice of the driving signal is determined by the position of

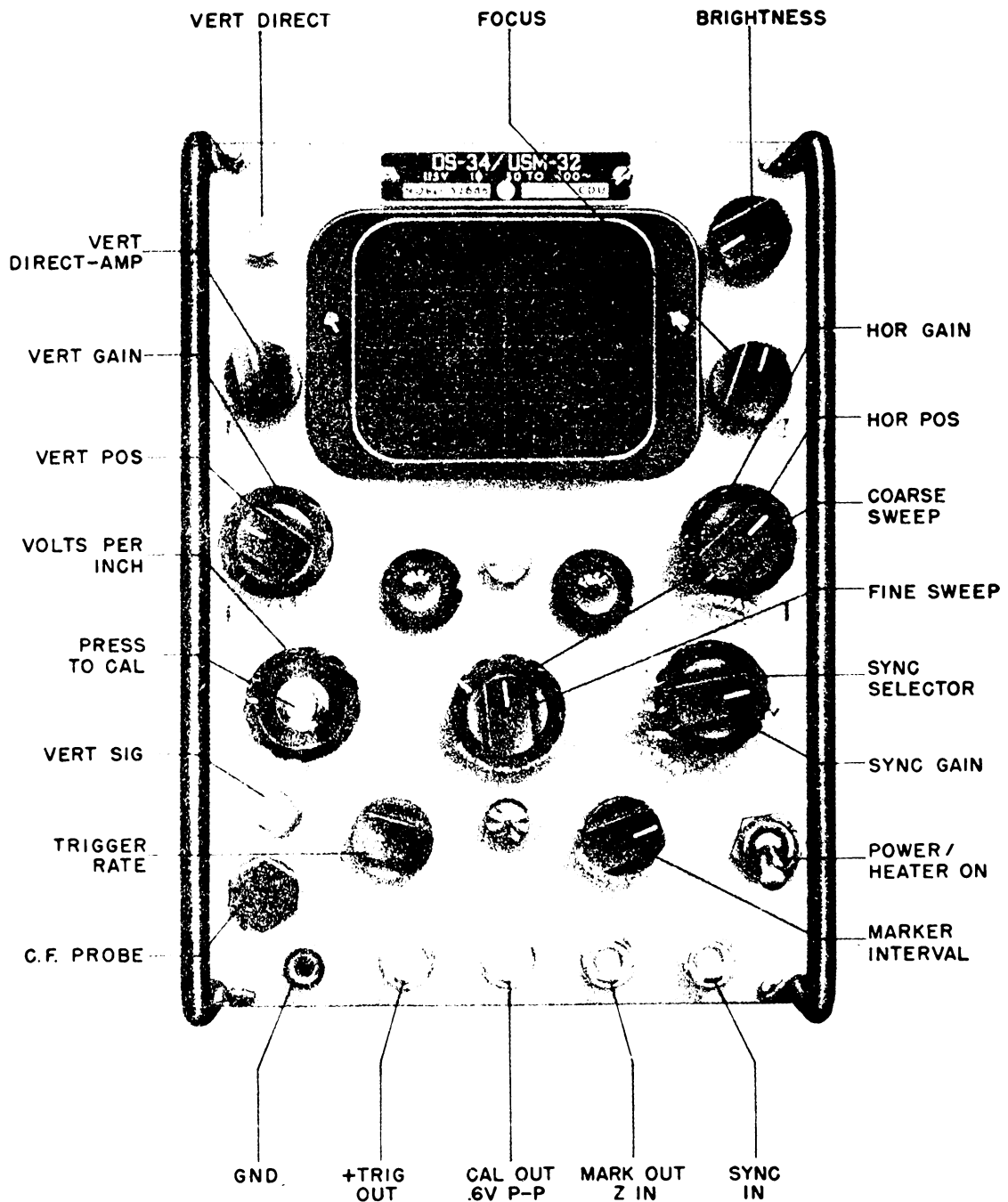
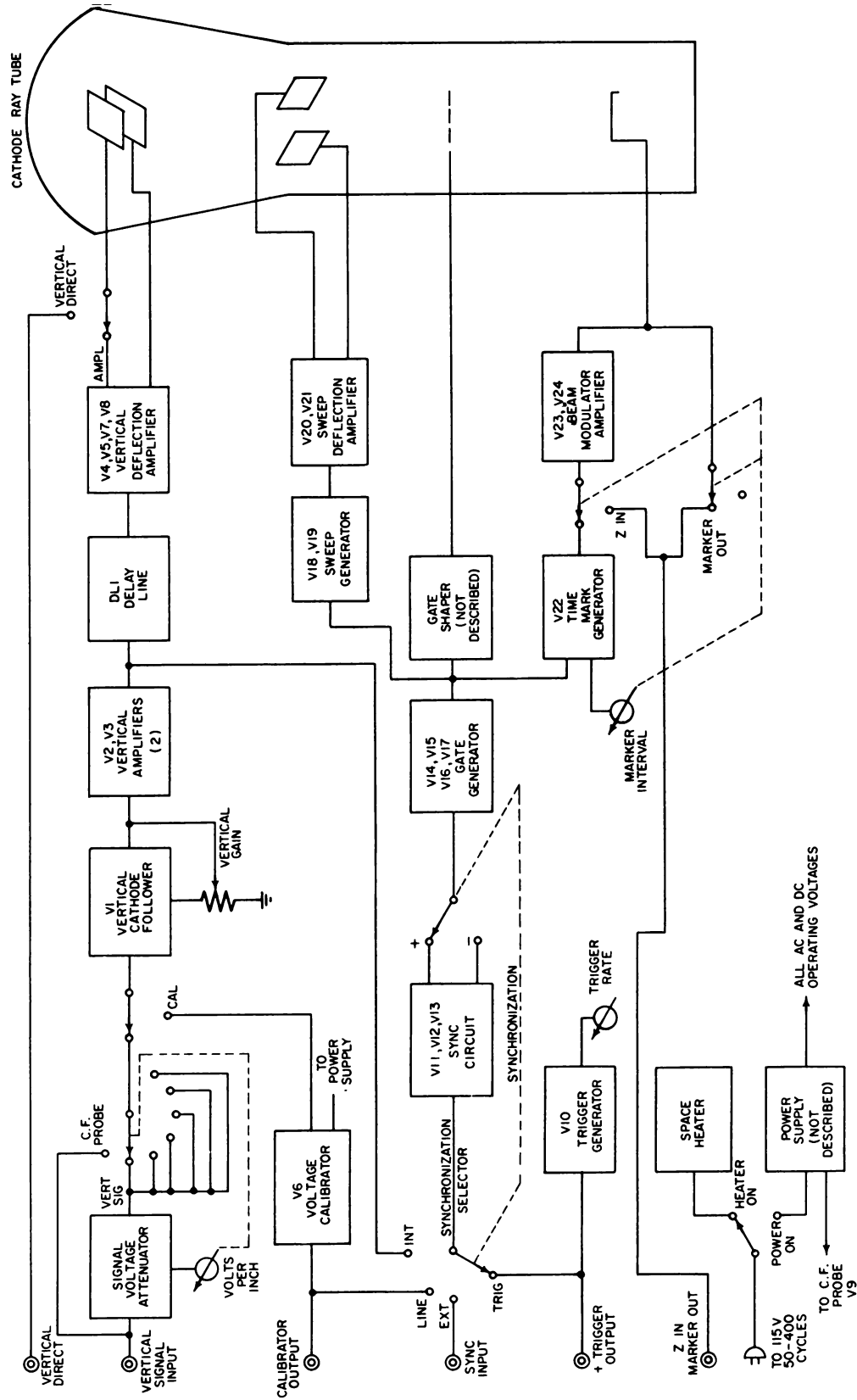


Figure 13-16. —Front panel of the oscilloscope AN/USM-32.

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the synchronization switch. The sweep duration is continuously variable from 10 to 200,000 μ s. The beam is brightened during the forward portion of the sweep.

Time calibration signals are provided for accurate time measurement of the visual presentation. Timing marker intervals of 1, 10, 100, 1000, and 10,000 μ s may be selected by the



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Figure 13-17.—Synchroscope block diagram.

marker interval control on the oscilloscope front panel. The markers are available at the cathode-ray tube cathode, and at the MARK-OUT/Z-in terminal for external use when the marker interval control is in any position except Z-in. When the control is in the Z-in position, external timing signals may be connected to this terminal to give markers on the sweep trace. Positive pulses applied to the MARK-OUT/Z-in terminal will produce blanking markers on the oscilloscope screen, and negative pulses will produce brightening markers.

The trigger generator supplies the internal trigger pulse for the sweep circuit when the synchronization control is in the TRIGGER position (as shown). The signal is also available at the +trigger-out terminal for external test purposes. The duration of the output trigger pulse is approximately two microseconds, and has a repetition rate that ranges from 45 cycles to 5.5 kilocycles, as determined by the setting of the trigger rate control.

The built-in voltage calibrator provides a method of making quantitative amplitude measurements of the vertical input signal. The circuit produces a square-wave calibrator signal, which is available internally, and may be substituted for the vertical input signal by depressing the press-to-cal pushbutton on the front panel. In this manner, the unknown signal can be compared with the known signal (calibrator) voltage to determine its amplitude. The signal is available at the calibrator output terminal at all times.

Regulated potentials of +110 v and -87 v, as well as +310 v and -1700 v unregulated, are obtained from the power supply for use in the circuits of the oscilloscope. A 6.3-v, a-c source is contained in the power supply for servicing the various tube heaters and the power indicator lamps on the front panel.

The power supply circuit is a conventional electronically controlled source. The operation of these circuits is considered in chapter 3 of Basic Electronics, NavPers 10087-A, and is not repeated here.

SIGNAL MEASUREMENTS

Amplitude Calibration

Amplitude measurements of the vertical signal may be made through the use of the built-in voltage calibrator, as previously discussed. The

signal from the voltage calibrator is substituted for the input signal by depressing the press-to-cal pushbutton.

When calibrating the oscilloscope, the vertical gain control must be set to its fully clockwise position. Thus, the position of the volts-per-inch control alone will affect the magnitude of the signal fed to the vertical amplifier stages.

Since the frequency of the calibrating voltage is the same as the line frequency (as discussed) the synchronization selector switch should be placed to either its + or - LINE positions. The 20K-2K position of the sweep time (coarse) control may be used. The position of this control is arbitrary since it only determines the number of cycles appearing on the cathode-ray screen. The synchronization (gain) control determines the magnitude of the synchronizing voltage, and must be advanced sufficiently clockwise to trigger the sweep circuits.

The press-to-cal pushbutton should now be depressed and the sweep time (fine) control adjusted for several cycles of the calibration pattern. Set the vertical gain control to give two inches of deflection on the cathode-ray screen. Do not change the position of the vertical gain control after it has been set for signal amplitude measurements. If it is accidentally moved, it must be reset through the same procedure.

The peak-to-peak voltage connected to the vertical signal terminal may now be determined. First, note the signal deflection in terms of inches on the cathode-ray screen. Secondly, multiply this reading by the volts-per-inch selector switch setting. For example, if the volts-per-inch switch is set to the 3 position, a deflection of 1.5 in. will represent 4.5 v.

The screen may be calibrated for other values of volts-per-inch than those indicated on the volts-per-inch selector switch. If the vertical gain control is adjusted to give one inch of calibrator square-wave deflection, the scale will be calibrated for 0.6, 2, 6, 20, 60, or 200 volts-per-inch at the respective volts-per-inch selector settings.

Use of Test Probes

The cathode follower probe (fig. 13-18) is employed where an especially high impedance and low shunting capacity must be presented to critical circuits being tested. The probe attenuates the input signal approximately 30%.

To make quantitative measurements when the cathode follower probe is being used, use

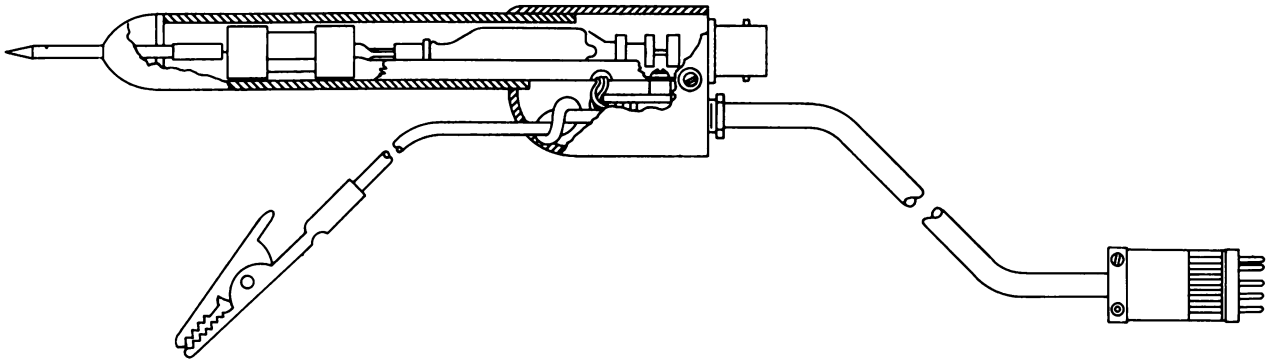


Figure 13-18.—Cathode follower probe, pictorial diagram.

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special calibration procedures as follows: touch the probe tip to the CAL-out terminal (fig. 13-16), which provides a 0.6-v peak-to-peak signal. Adjust the vertical gain control for 0.6-v, peak-to-peak, full-scale (2 in.) deflection.

A maximum signal of 2 v rms may be investigated by the cathode follower probe without distortion. The 2-v signal may be superimposed on a d-c level as high as 600 volts.

The attenuator probe (fig. 13-9A) is employed where negligible loading of a high impedance circuit is important, and where sufficient signal amplitude is present to allow an attenuation of the impressed signal by 20:1. With the same impedance requirements, the attenuator probe should be employed in those applications where the cathode follower probe would not be suitable.

The maximum permissible a-c signal input for the attenuator probe is 600 v peak-to-peak. Any signal coupled to the probe is attenuated 20:1, and this ratio should be kept in mind when

the built-in voltage calibrator is employed for amplitude measurements.

The signal cable for the attenuator probe is permanently attached to the probe since the cable capacity (fig. 13-19B) forms part of the frequency compensation circuit of the probe. For normal signal input applications, the probe is connected to the vertical signal terminal. However, it may also be connected to the vertical direct, the marker out Z in, or the sync-in terminals.

The detector probe (fig. 13-20A) will demodulate a-m signals in the range from 10 cycles to 15 kc over a carrier frequency range of 0.5 to 400 mc. The audiofrequency response is within 6 db at any carrier frequency in the operating range.

The peak inverse voltage of the crystal (fig. 13-20B) is 125 v. Signal voltages to be demodulated by the detector probe should not exceed this value.

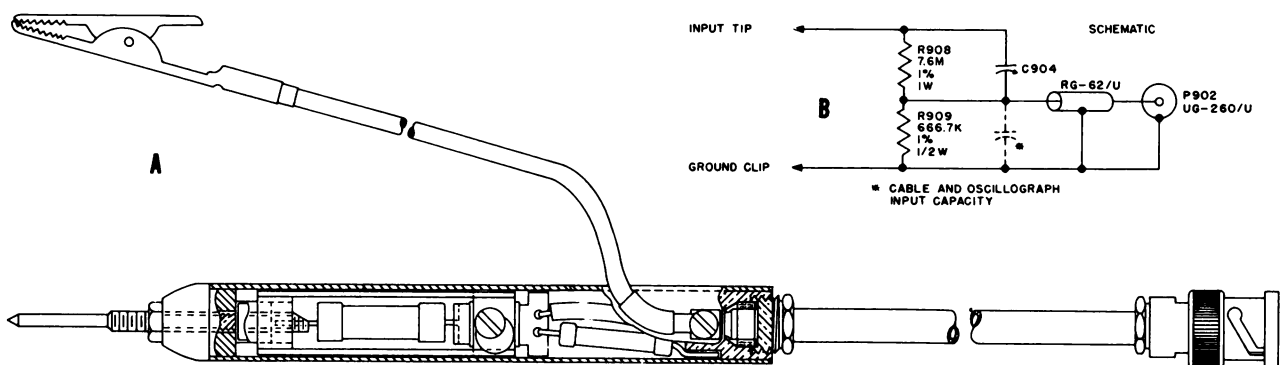


Figure 13-19.—Attenuator test probe.

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Adapter Connector

The adapter connector (not shown) enables the operator to connect wire type test leads to the coaxial terminals on the front panel. Set knobs are provided on the adapter for tightening the wire leads.

SPECTRUM ANALYZER

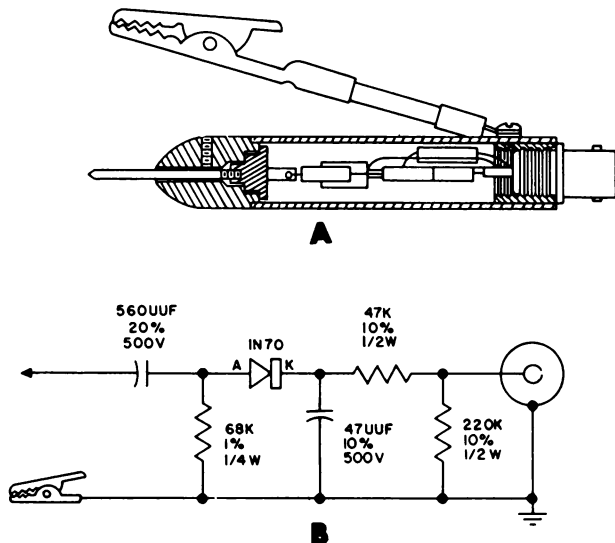
A spectrum analyzer is a device that sweeps over a band of frequencies to determine (1) what frequencies are being produced by a specific circuit under test and (2) the amplitude of each frequency component. To accomplish this, the spectrum analyzer presents, on an oscilloscope display, a pattern in which the relative amplitudes of the various frequencies of the spectrum are plotted on the vertical, or Y axis, while the frequencies themselves are plotted on the horizontal, or X axis, of the cathode-ray tube. The overall pattern of this display indicates the proportion of power present at the various frequencies within the spectrum. A representative spectrum analyzer equipment is the AN/UPM-33, which consists of the TS-148/UP Spectrum Analyzer with carrying case and accessories.

The control panel of the TS-148/UP spectrum analyzer is shown in figure 13-22. The circuits of this unit will be discussed in this section since they represent to a great extent spectrum analyzer circuits in general.

The spectrum analyzer can be used to examine the spectra of magnetrons, local oscillators, test sets, and other equipment operating within its frequency range. A frequency meter is used to measure accurately the frequencies of any of the above equipments, or to set the frequency of radar and beacon local oscillators in radar sets. The spectrum analyzer can also be used as a f-m oscillator to tune T/R boxes and ATR boxes in transmitters.

COMPONENTS OF A SPECTRUM

A common conception of the output of a pulsed oscillator is a single frequency, which is turned on and off for periods of standard duration. This action is similar to the output of a conventional c-w telegraph transmitter. The output of the pulsed radar oscillator does not consist of a fundamental frequency that is turned on and off, but must be considered as a

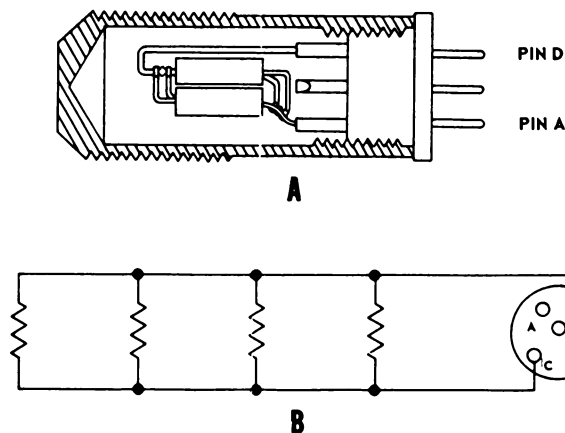


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Figure 13-20. —Detector test probe.

To use the detector probe, connect one end of the r-f cable (provided with the equipment) to the vertical signal terminal and the other to the probe. Apply the probe tip to the circuit under test.

The resistor assembly (fig. 13-21A) is a plug-in adapter that connects to the cathode follower probe socket. When plugged in, it provides 75-ohm termination (fig. 13-21B) for the vertical signal terminal in all positions of the volts-per-inch switch.



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Figure 13-21. —Resistor assembly.



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Figure 13-22.—Spectrum analyzer control panel.

fundamental frequency that is pulse modulated by the waveform of the trigger pulse.

Effects of Modulating Pulses

When modulated, any fundamental frequency will produce a fundamental frequency with side-band frequencies, which collectively is called a spectrum. The distribution of the power on these frequencies is a function of the modulation. Normally, modulation is plotted on an amplitude and time basis as shown in figure 13-23B, C, and D.

Assume F to be the fundamental frequency of the oscillator. Waveform A shows the fundamental frequency plotted as amplitude against time. The number of periods occurring within one second determines the frequency of the oscillation. The amplitude is represented as proportional to the distance between the negative and positive peak of one cycle.

In a spectrum pattern, this same frequency and amplitude would be represented as F in

figure 13-23E. Points along the horizontal axis represent frequency, which increases from left to right, while distance along the vertical axis above the baseline represents amplitude. Thus, two methods of diagramming the results of amplitude-modulating a carrier frequency are shown.

Assume that F_p is a modulation frequency applied to the fundamental frequency, F . This is normally represented on an amplitude-versus-time basis (fig. 13-23B). This same type of modulation is shown by two lines on the spectrum pattern. These lines are marked $F+F_p$ and $F-F_p$ in figure 13-23E. The reason for this is that the modulated wave actually represents the results of heterodyning two different frequencies. These frequencies are effectively present in the modulated output, and can be detected by suitable receivers. One of the frequencies is the sum of the two, and the other is the difference. The amplitudes of the new frequencies are each half the amplitude of the peak-to-peak value of the modulating frequency.

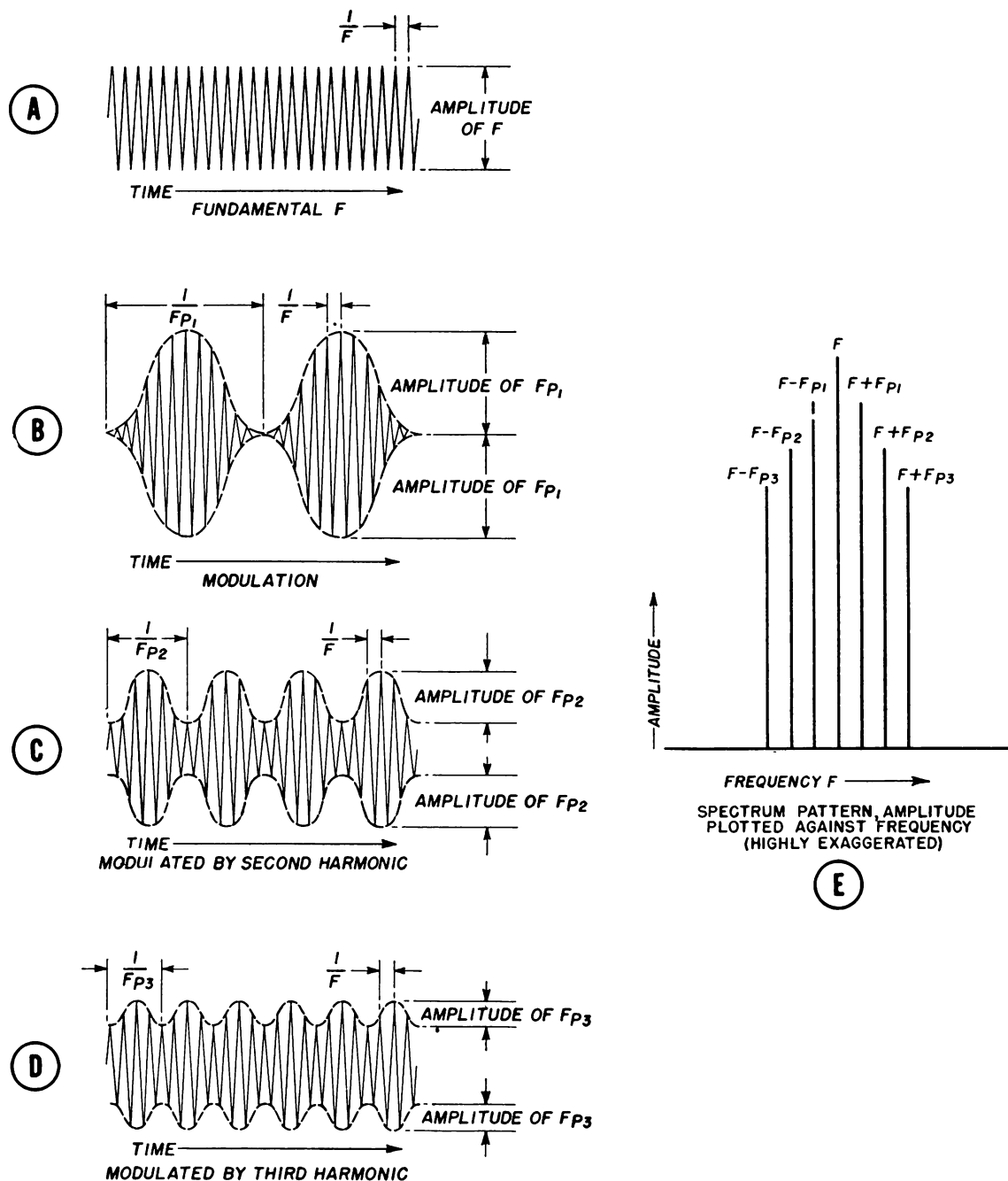


Figure 13-23.—Comparison of amplitude vs time to amplitude vs frequency.

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Assume also that a second harmonic of the modulating frequency exists. This is usually of a smaller amplitude than the fundamental of the modulating frequency. Another set of waves will be developed as at C for amplitude-

versus-time, and at $F + F_{p2}$ and $F - F_{p2}$ on the spectrum pattern.

Additional modulating frequencies will produce additional sideband frequencies. Since these frequencies are normally present in a

harmonic relationship, the net result is a number of different frequencies above and below the carrier. The difference between any two adjacent frequencies is equal to the fundamental modulating frequency.

Spectrum of a Pulsed Oscillator

Usually a pulse modulated oscillator is pulsed by the application of a rectangular wave of voltage to an oscillator circuit. A narrow rectangular wave contains an exceedingly wide range of harmonics, including harmonics of a very high order. Consequently, a pulsed oscillator may be assumed to be an oscillator modulated by a modulation frequency that is exceedingly rich in harmonics.

The pulse frequency and the basic frequency of the pulsed oscillator are shown on an amplitude-versus-time graph (fig. 13-24). From this figure it might appear that the output is simply a pure c-w wave of constant amplitude and frequency, turned on for brief intervals of time. This concept cannot be true because of the presence of the modulation frequency F_p , and the very large number of harmonics (of the modulating frequency) F_{p2} , F_{p3} , etc., as discussed. Therefore, the fundamental modulation frequency and its many harmonics may be considered to modulate the oscillator to produce a fundamental frequency with many sidebands. The net result is a spectrum such as was developed in figure 13-23E, except that it is extended to a very large number of frequencies above and below the fundamental frequency. Such

a spectrum is shown in figure 13-25A, along with the pulse that produced the spectrum in figure 13-25B. It is shown that the output of the oscillator consists of an infinite number of lines representing different frequencies. However, because of the harmonic relationship between the modulation frequency and its harmonics, these lines will always be separated by a distance on the baseline that is equal to the fundamental modulation frequency, F_{p1} .

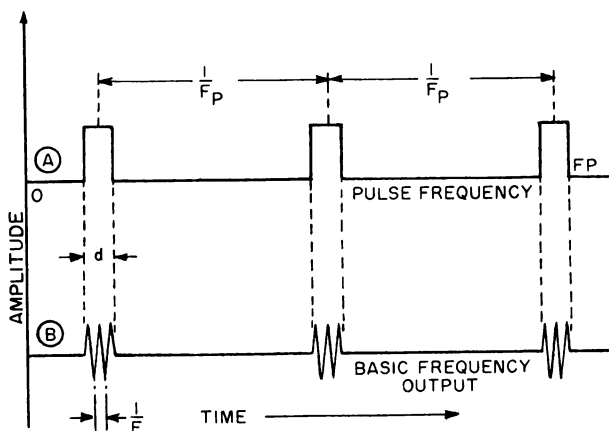
The amplitude-versus-frequency plot provides an envelope, which is of value in estimating the power distribution in the output of a pulsed oscillator. This spectrum, as plotted on the spectrum analyzer, is a power spectrum produced by the square law characteristics of the detector discussed later. The true power spectrum, which represents the voltage (or amplitude) squared (E^2), is shown in figure 13-25D.

The power spectrum emphasizes the importance of confining the majority of the power at the fundamental frequency of the pulsed oscillator. The spectrum analyzer can be used in tuning up a radar transmitter so as to provide the greatest range of power output in the band-pass circuits of a receiver.

Figure 13-25C, represents a sample of the spectrum (fig. 13-25A). The figure shows the effective voltage derived from the oscillator frequency spectrum. We can conclude that the pulsed oscillator output contains both frequency and amplitude components. The effect of amplitude modulation is to increase the number of sidebands in the spectrum. The effect of frequency modulation is to increase the amplitude of the side lobes, since the frequency of the oscillation is effectively shifted back and forth between points on each side of the true fundamental frequency.

BLOCK DIAGRAM

Basically, the spectrum analyzer consists of a superheterodyne receiver with a frequency-modulated, r-f oscillator (fig. 13-26). The analyzer r-f oscillator is modulated with a sawtooth voltage, which causes the oscillator to operate over a range of frequencies. As the frequency of the analyzer r-f oscillator increases, it beats with the incoming signal to produce an i-f signal for various frequency components present in the spectrum of the received signal. These signals are presented on a cathode-ray oscilloscope as the spectrum pattern.



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Figure 13-24.—Output of a pulsed oscillator.

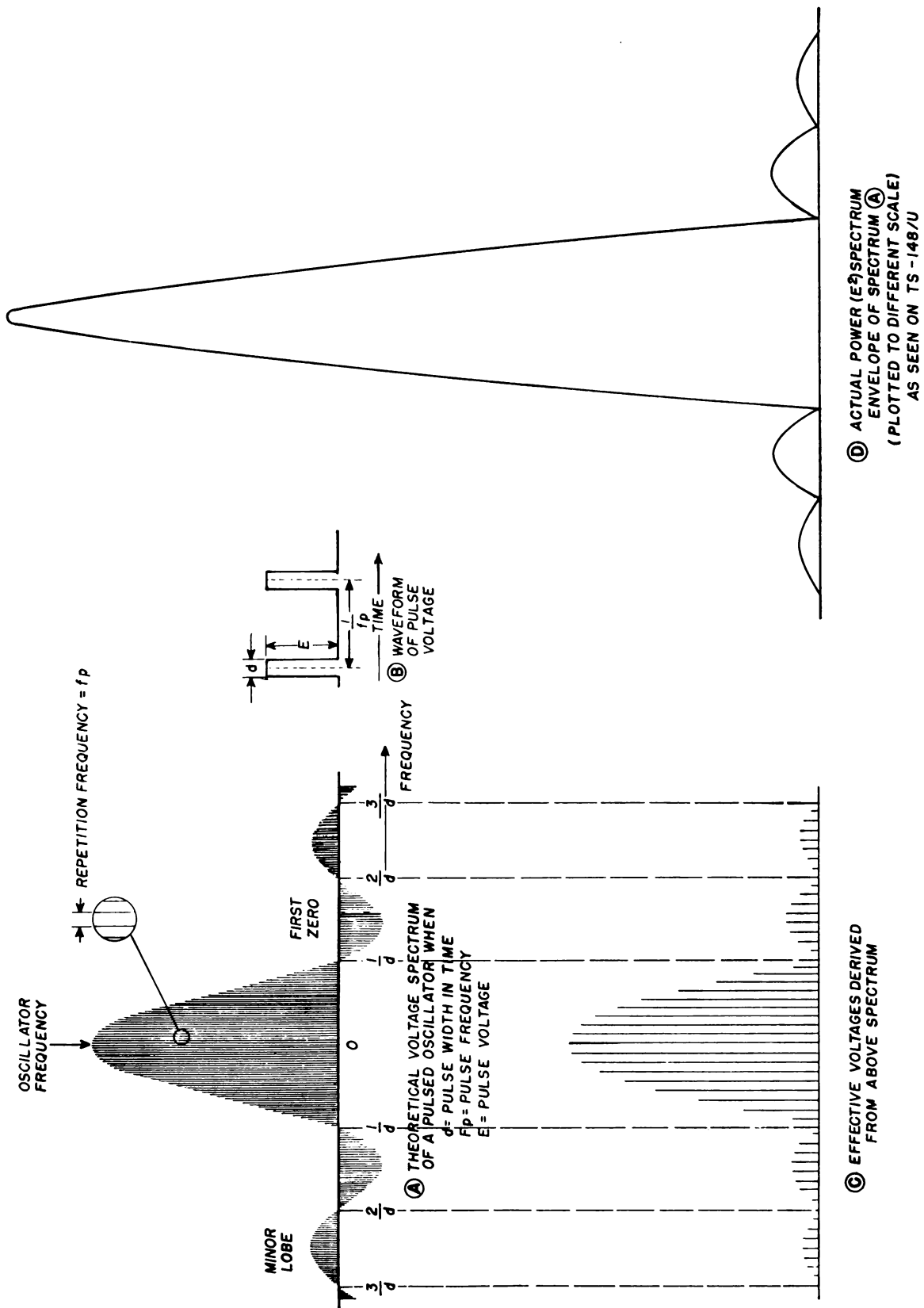
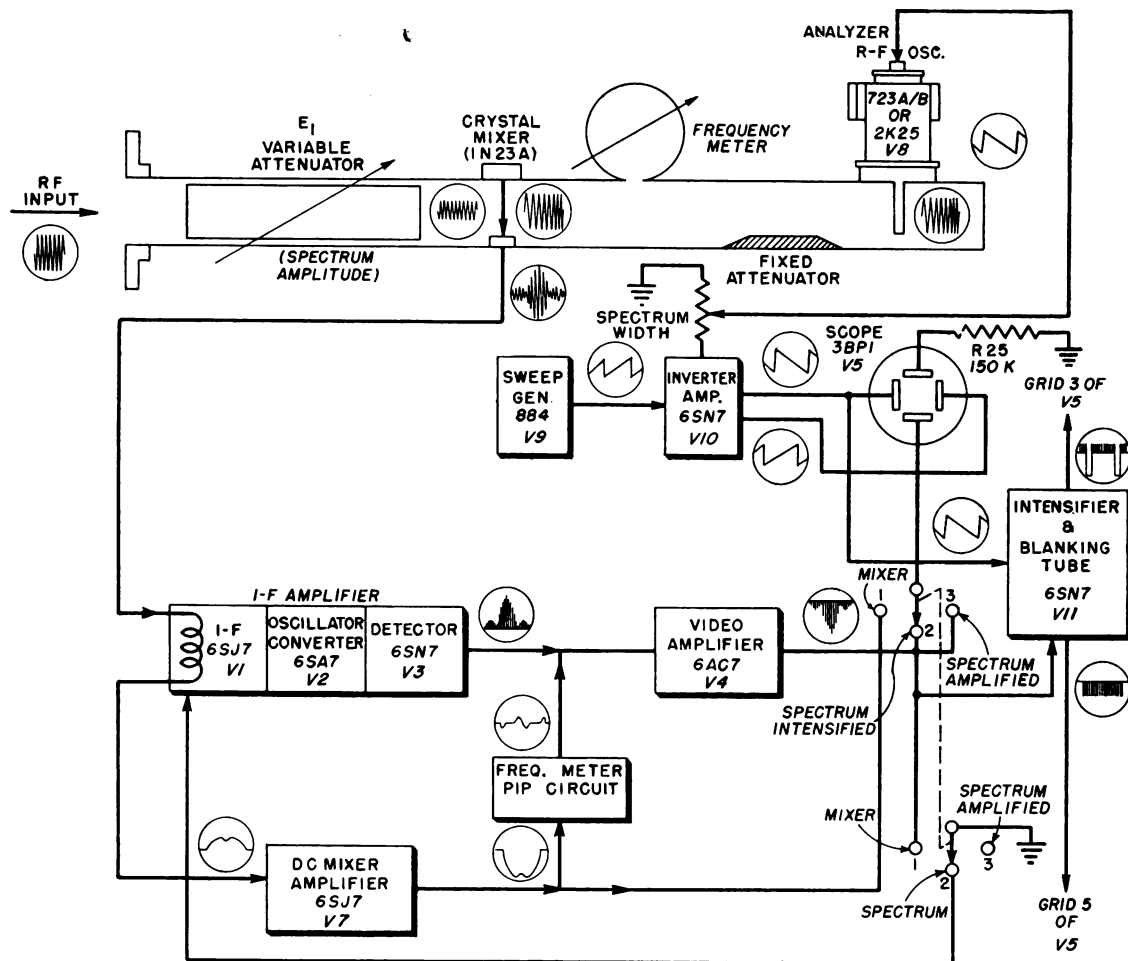


Figure 13-25.—Relationship between a voltage spectrum and a power spectrum.



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Figure 13-26.—Spectrum analyzer block diagram.

A block diagram showing waveforms is shown in figure 13-26. The r-f input is applied to a variable attenuator. The attenuator controls the spectrum amplitude, and consists of two carbonized resistance cards inserted in the r-f input end of the waveguide. Varying the contour of these cards varies the degree of attenuation. Maximum attenuation is obtained when the cards are flexed together in the center of the waveguides. The attenuator controls the amplitude of the r-f signal either entering the analyzer, or leaving the analyzer when it is used as a signal generator.

The analyzer r-f oscillator is a reflex velocity-modulated klystron. It is frequency modulated by a portion of the sweep voltage, which is applied to the oscilloscope deflection plates. The sweep voltage creates a maximum

frequency swing in the oscillator output of 40 to 50 mc. The analyzer r-f oscillator output is matched to the load by the fixed attenuator in the waveguide.

The incoming signal and the output of the r-f oscillator are mixed at the crystal mixer. The output is applied to the input circuit of the tuned i-f amplifier section to produce the intermediate frequency of 22.5 mc.

An absorption type frequency meter is mounted in the waveguide at a point between the crystal and the r-f oscillator. The meter consists of a cavity with dimensions that can be varied by a front panel control. Each time the frequency of the r-f oscillator passes through the resonant frequency of the frequency meter, the meter absorbs some of the r-f power. This causes a sharp decrease in the amplitude of

the output of the r-f oscillator that is applied to the crystal. The change in amplitude is caused to appear on the scope as a sharp pip, which is used as a frequency marker. The pip occurs when the frequency of the r-f input coincides with the frequency of the meter.

The output of the crystal mixer is applied to the input circuit of the 22.5-mc intermediate frequency amplifier. The output of the i-f amplifier section is applied to the oscillator-converter.

The oscillator-converter contains a local oscillator operating at a frequency of 19.5 mc. The intermediate frequency is changed to three megacycles in this stage by beating the 19.5-mc frequency against the 22.5 mc from the crystal mixer. The sharply tuned plate circuit of the oscillator-converter produces a 50-kc circuit bandpass. The output is applied to the detector stage.

The detector section functions as an infinite impedance detector. The rectified output of the detector is applied to the video amplifier.

The video amplifier stage has two inputs. One is the output of the detector, and the other the frequency meter pip obtained from the d-c amplifier through a differentiating circuit. The output of the video amplifier is coupled to the vertical deflecting plates of the oscilloscope. A portion of the video output is used to trigger the intensifying stage.

When the selector switch on the front panel is in the MIXER position (position 1), the d-c mixer amplifies the output of the crystal mixer and applies it through the selector switch to the vertical plates of the cathode-ray tube for test purposes. In the other two positions of the selector switch, the output of the d-c mixer is applied to the video amplifier. The end pips of the waveshape appearing at the video amplifier grid are derived by differentiation in the plate circuit of the d-c mixer amplifier. The center pip corresponds to the point of resonance of the frequency meter.

The sweep oscillator is a gas tube relaxation oscillator that generates a saw-toothed output at frequencies between 10 and 30 cps. The output of the sweep oscillator is used to drive the sweep inverter amplifier.

The sweep inverter amplifier provides push-pull deflection voltages for the horizontal plates of the cathode-ray tube. It also supplies modulating voltage to the analyzer r-f oscillator and trigger voltage for the blanking section.

When the selector switch is placed in either of the SPECTRUM positions (positions 2 or 3 on the front panel), the video amplifier signal triggers the intensifier tube. The output thus produced is coupled to the intensifying grid of the cathode-ray tube.

The input voltage from a section of the sweep inverter amplifier is used to trigger the blanking tube. The output of this tube is applied as blanking voltage to eliminate the return trace that would otherwise appear on the scope screen.

PROCEDURE FOR OBSERVATION OF SPECTRA

Magnetron or Other Oscillator Spectra

Assuming that the spectrum analyzer has been installed and turned on, the selector switch (fig. 13-22) should be placed in the MIXER position. In this position of the switch, adjustments may be made on the analyzer r-f oscillator. The spectrum width control should be turned in a clockwise direction until its setting is nearby maximum.

After all necessary adjustments have been made on the analyzer, and the desired width of the scope trace is set, place the selector switch in the SPECTRUM or SPECTRUM AMPLIFIED position. Use the spectrum amplifier position if there is no likelihood of interference from any adjacent radar equipment. If interference occurs, spectrum position should be used.

Point the waveguide, which is accessible through the side door shown in figure 13-22, at the radar antenna or to the magnetron output. Coupling the waveguide too close to the source will burn out the attenuator and crystal mixer in the analyzer. Likewise, if the coupling is too close, the probability of magnetron pulling is increased.

An antenna horn and fittings (component parts of the TS-148/UP) may be used if the former method does not supply satisfactory results (fig. 13-27). This method can be used to pick up the output of the magnetron at distances up to 100 ft if the two antennas are pointing directly at each other.

The operator should never attempt to increase the amplitude of the spectrum trace by increasing the coupling until it is ascertained that the amplitude cannot be increased by adjusting the spectrum amplitude control (attenuator) or by placing the selector switch in

WARNING! DO NOT COUPLE THIS CLOSELY OR SERIOUS DAMAGE WILL RESULT.

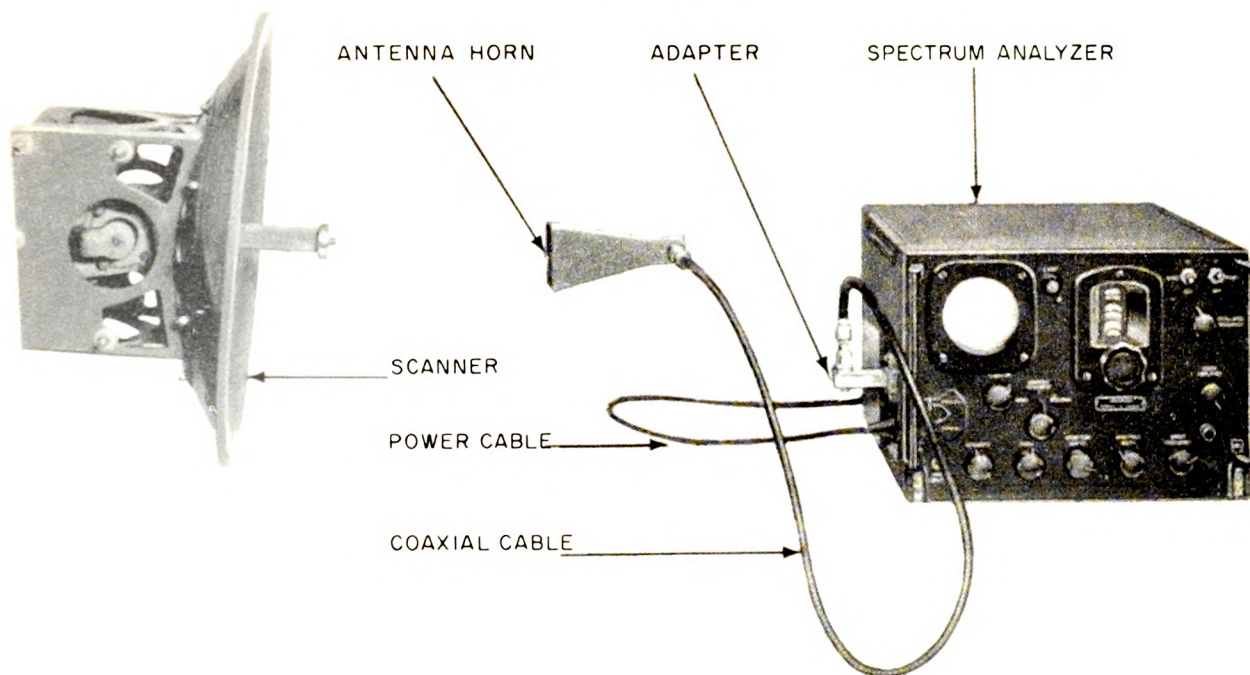


Figure 13-27.—Use of antenna horn.

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its SPECTRUM AMPLIFIED position, or both. To do so would burn up the resistance cards in the attenuator and burn out the crystal, even though the equipment is turned off.

The antenna horn should be pointed directly to the source under test. In the case of an oscillator, it is seldom necessary to remove the oscillator cover. The magnetron and local oscillator spectrums may be observed simultaneously if a proper location for the antenna horn is found that produces sufficient attenuation to the output of the magnetron.

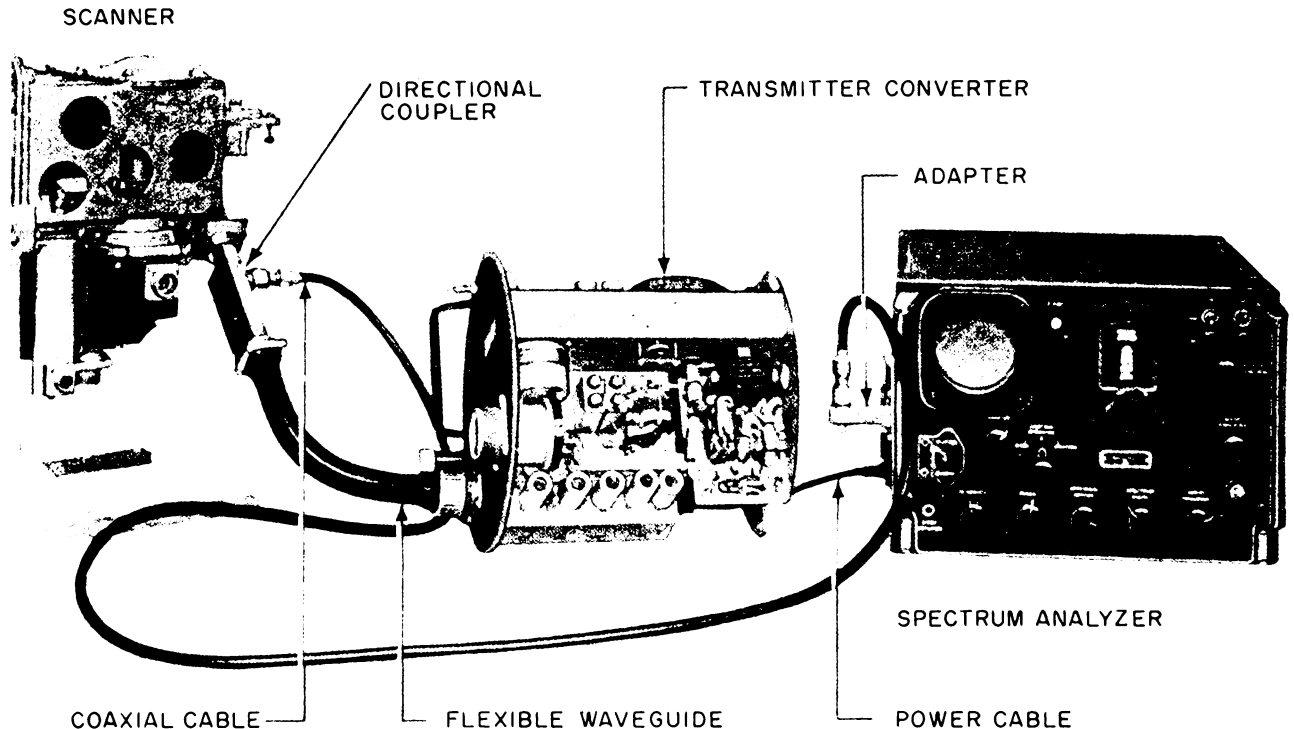
If a very stable method of coupling is desired, remove the antenna horn and connect the cable to the directional coupler or wave selector (fig. 13-28), which is inserted at some convenient place in the transmission line of the radar equipment. The spectrum analyzer will then receive approximately one percent of the power in the directional coupler. This method is very satisfactory when it is necessary to check the antenna while it is in motion to see if it is pulling the frequency of the magnetron.

Observation of Patterns

Adjust the spectrum amplitude control to obtain the desired amplitude on the screen. Rotate the spectrum width control counterclockwise until the spectrum gains sufficient detail to make observation easy. If more pulses are desired in the spectrum, turn the sweep frequency control counterclockwise to a lower sweep frequency.

FREQUENCY MEASUREMENT

The frequency meter pip that is visible when the selector switch is in the MIXER position (fig. 13-29) represents the actual frequency of the frequency meter, as read on the frequency meter dial. When the selector switch is in either of its other two positions for frequency measurements, the reading on this dial does not represent the frequency being measured. The unknown frequency must be computed from the dial reading by adding or subtracting the 22.5-mc intermediate frequency of the analyzer.



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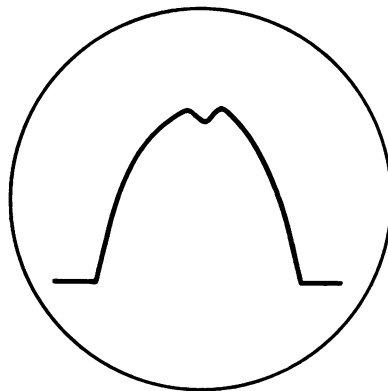
Figure 13-28.—Use of the directional coupler.

Whether the intermediate frequency is added or subtracted depends on which image the frequency meter pip is made to coincide. Two

images will appear for each component of the spectrum (fig. 13-30). The frequency of the analyzer r-f oscillator increases as the sweep progresses from left to right across the screen. This action causes an image to be produced below and above the 22.5-mc intermediate frequency. In most cases, both images can be made to appear on the screen although, in actual practice, one is centered on the screen so that the other does not appear.

If the image selected for frequency determination is the one on the right, it is necessary to subtract 22.5 mc from the dial reading. The remainder thus obtained represents the frequency of the unknown signal. If the left image is selected, it is necessary to add 22.5 mc to the dial reading. Since the two images appear above and below the true frequency by 22.5 mc, it is obvious that the two readings may be made directly from the meter, and the average taken to obtain the unknown frequency.

Another very accurate method may be used if the unknown signal is stably coupled to the analyzer. The method consists of tuning the frequency meter until its pip is equidistant from the two images (fig. 13-31). While tuning the meter, both images must be carefully observed. At the instant the resonant frequency

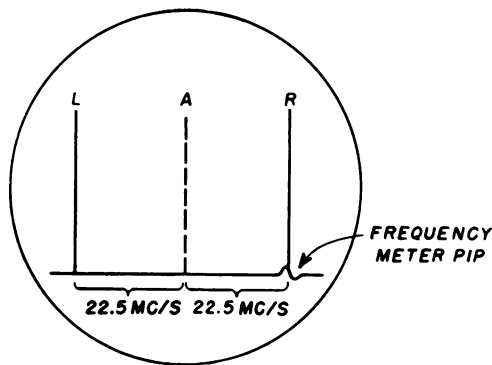


a. MIXER POSITION

NO SIGNAL PRESENT EXCEPT
THAT OF ANALYZER R-F
OSCILLATOR

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Figure 13-29.—Frequency meter pip (selector switch in MIXER position).



92.143

Figure 13-30.—Right- and left-hand patterns.

of the frequency meter equals the frequency of the unknown signal, it will be possible to see both images dip simultaneously. The reduction in amplitude occurs because the frequency meter absorbs energy from the unknown signal frequency. In this case, the reading on the frequency dial represents the actual frequency of the unknown signal.

MEASUREMENT OF RADAR LOCAL OSCILLATOR FREQUENCY

There are two similar methods for measuring the frequency of a radar local oscillator. The choice of methods depends upon whether the intermediate frequency is 30 mc or 60 mc/s.

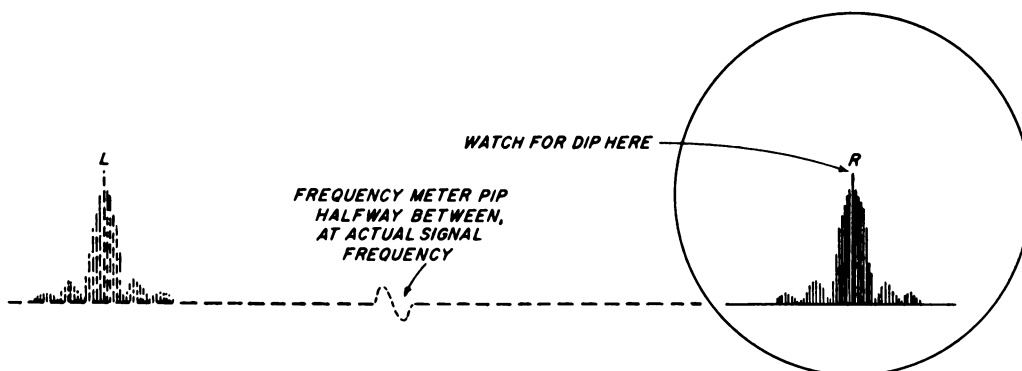
Assume that the radar intermediate frequency is 60-mc, and that the local oscillator frequency is above that of the magnetron. It should be noted that two frequencies 60 mc apart cannot be seen

on the same scope trace. This is true because the full width of the i-f above and below the analyzer radio frequency is only 45 mc wide (fig. 13-32). In order to see both patterns simultaneously, a unique use is made of the fact that two spectrum images appear for each signal. In practice, the spectrum center control is used to make the right-hand spectrum of the magnetron appear on the left side of the scope. The left-hand pattern of the radar local oscillator should then appear to the right of this pattern. The pattern represented by the dotted lines in the figure does not appear on the scope, but is shown to illustrate the frequency relationship of the two images that do appear.

The accuracy with which the radar local oscillator tracks the magnetron can be determined by measuring the difference between the frequencies of the two images on the screen. This difference should be 15 mc (using the lower magnetron image as the reference). To determine the actual difference, rotate the frequency dial to set the frequency meter pip under the center of the magnetron spectrum, and note the dial reading. Then set the pip under the radar local oscillator pip, and again note the dial reading. If the difference between the dial readings is 15 mc/s, the radar local oscillator (or AFC discriminator) has been accurately set to follow the excursions of the magnetron frequency.

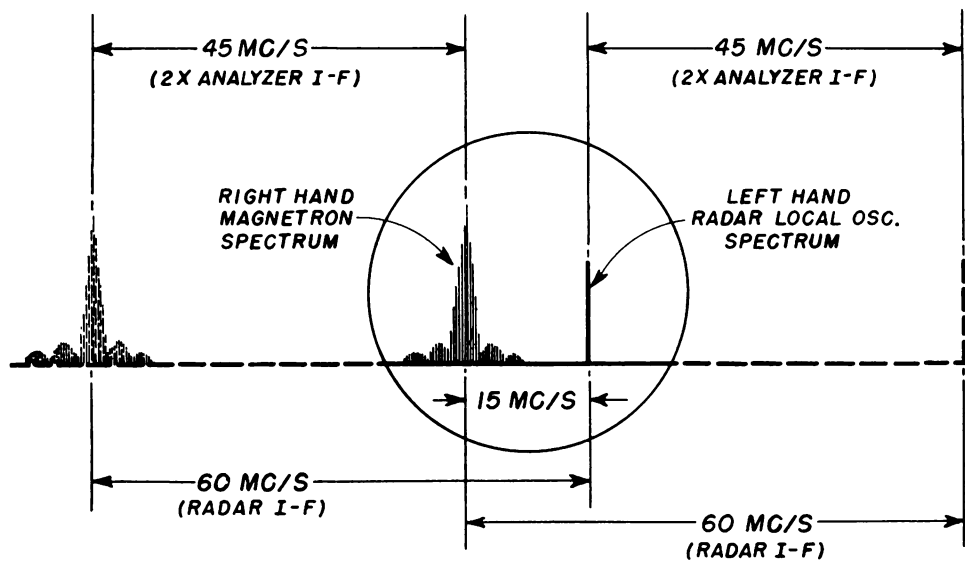
If the frequency of the radar local oscillator is set 60 mc below the magnetron frequency, the only effect is that the images will be reversed on the screen (fig. 13-33).

If the intermediate frequency is 30 mc/s above, the procedure is similar to that first



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Figure 13-31.—Determination of frequency by tuning frequency meter for dip in spectrum.

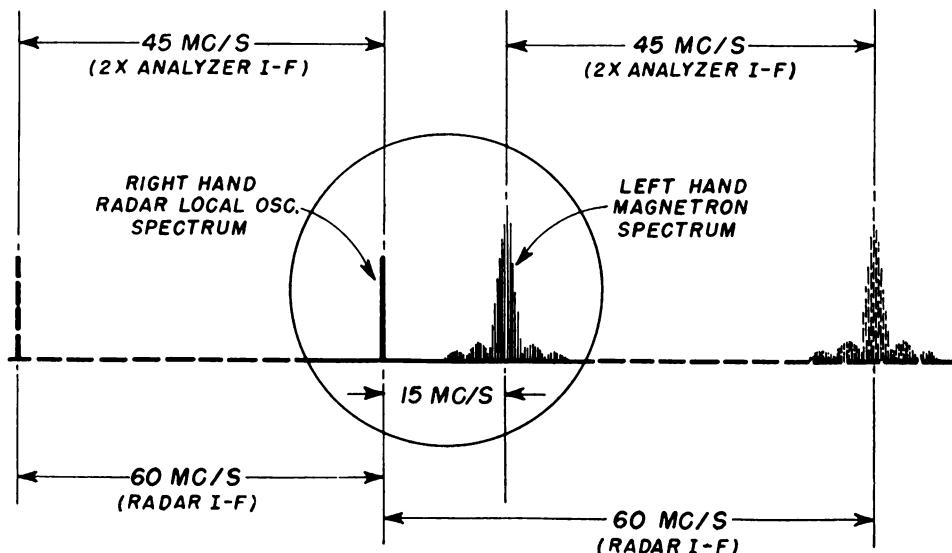


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Figure 13-32. —Measuring the frequency of a local oscillator that is 60 mc above the magnetron.

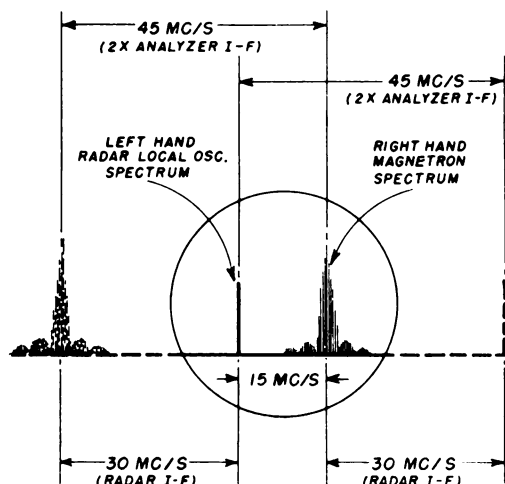
discussed, except that the position of the images is reversed (fig. 13-34). This is true since by time relationship, the left-hand spectrum of the radar local oscillator is made to appear on the

left side of the screen, while the spectrum of the magnetron now appears on the right. The difference in the frequencies is measured just as it was in the foregoing method, and a frequency



92. 146

Figure 13-33. —Measuring the frequency of a local oscillator that is 60 mc below the magnetron.



92.147

Figure 13-34.—Measuring the frequency of a local oscillator that is 30 mc above the magnetron.

difference of 15 mc/s indicates that the local oscillator is operating at a frequency 30 mc/s above the magnetron.

If the radar local oscillator operates below the magnetron frequency, the position of the images will again be reversed. That is, the radar local oscillator spectrum will be on the right and the magnetron spectrum on the left.

SPECTRUM ANALYZER USED AS A SIGNAL GENERATOR

The analyzer may be used as a c-w or f-m signal generator, depending upon whether the spectrum width control is set at either of its extreme positions. If it is set completely counterclockwise, the percent of frequency modulation is at a minimum (about 3 mc/s), and the output is essentially a c-w signal. If the control is turned all the way clockwise, the percent of frequency modulation is maximum, and the output has a width of from 40 to 50 mc, depending upon the condition of the tube in the analyzer r-f oscillator.

RANGE CALIBRATOR

Range Calibrator sets, such as those shown in figure 13-35, are portable test sets designed for use in testing and adjusting the accuracy of the range indicators of radar systems.

A second application of the range calibrator sets is to determine the delays present in the transmission lines of radar systems. A typical application is the determination of the delay existing in the waveguide path between the transmitter and the transmitting antenna.

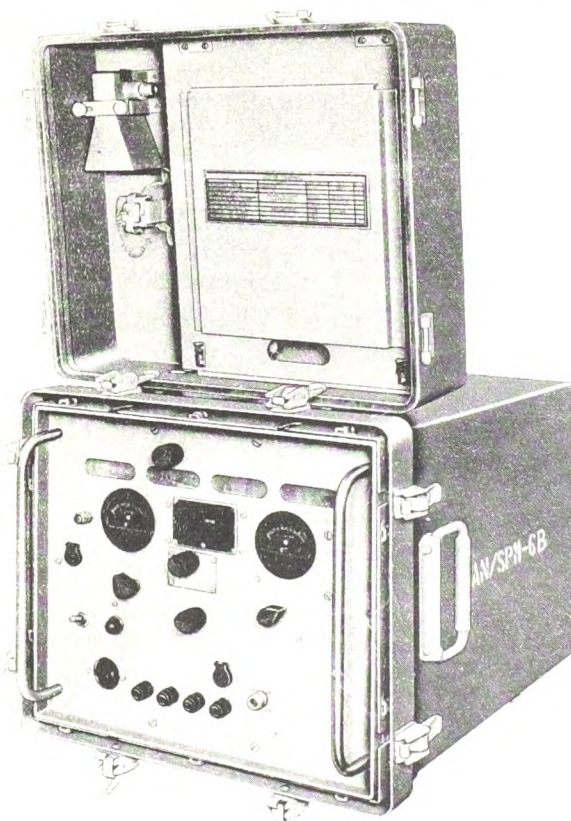
Typical radar range circuits determine target range by measuring the length of time a pulse takes to reach an object and be reflected back to the radar. To check the accuracy of the radar range circuits, the radar range indication can be checked against navigational range to target. Instead of using an actual target and physically measuring the range, the range calibrator set provides range information by receiving a transmitted pulse, delaying the pulse for a predetermined length of time, and retransmitting the pulse to the radar, thus simulating a return pulse with a measured delay.

When used with an operating radar, the range calibrator set produces a train of delayed echo pulses for each r-f input pulse received from the radar. Echo pulses are at the same frequency as the r-f input pulse, and are separated from each other by a fixed time delay nominally equivalent to 3600 yards of radar range. The only variance from this delay is found in the first echo pulse which is delayed from the radar r-f input pulse by a nominally equivalent radar range of approximately 1800 yards.

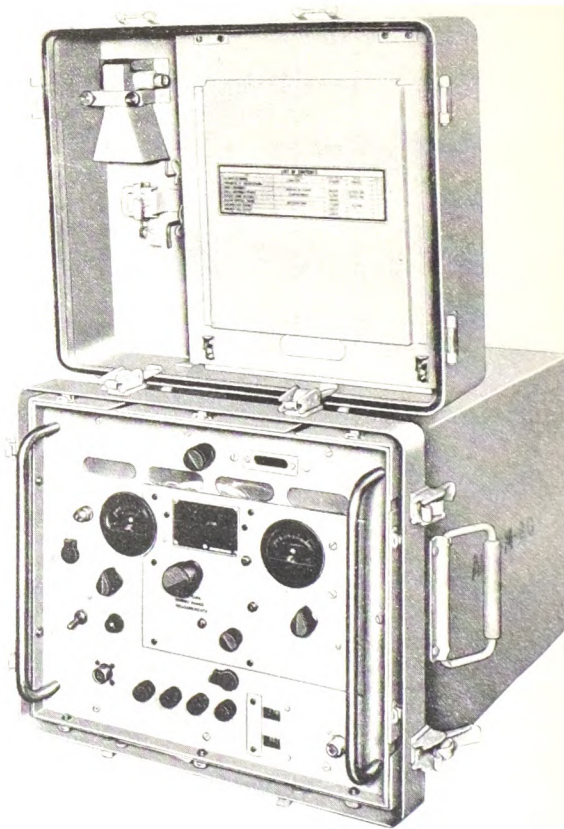
Range calibrator sets basically consist of an r-f transponder loop, which produces the delayed echoes, and an afc loop, which maintains the echoes at a fixed frequency.

The r-f transponder circuits (fig. 13-36) develop a train of pulses for use in testing the range accuracy of a tracking radar. The train of pulses is developed by taking the r-f pulse from the tracking radar and mixing it with a local oscillator signal to develop an i-f pulse which is fed to a delay line. The delay line develops a series or train of delayed echo pulses which are amplified and fed to a modulator, where they are mixed with the local oscillator signal to produce a train of pulses at the frequency of the input r-f signal. These r-f pulses are then fed back to the tracking radar for use in checking range accuracy.

THE DELAY LINE. The i-f pulses from the mixer are supplied to the delay line (fig. 13-37), which consists of a fused quartz rod to which the i-f pulses are electromechanically coupled by means of a piezoelectric crystal fixed to the end face. Because of the piezoelectric effect, a



RANGE CALIBRATOR SET AN/SPM-6B



RANGE CALIBRATOR SET AN/SPM-6C

92.148

Figure 13-35.—Range Calibrator Set AN/SPM-6B and Range Calibrator Set AN/SPM-6C.

mechanical vibration is set up in the rod. Disregarding for the moment the comparatively small (but not negligible) delay of the i-f amplifier, the time it takes the longitudinal wave to traverse the quartz rod represents the nominal delay of the range calibrator set.

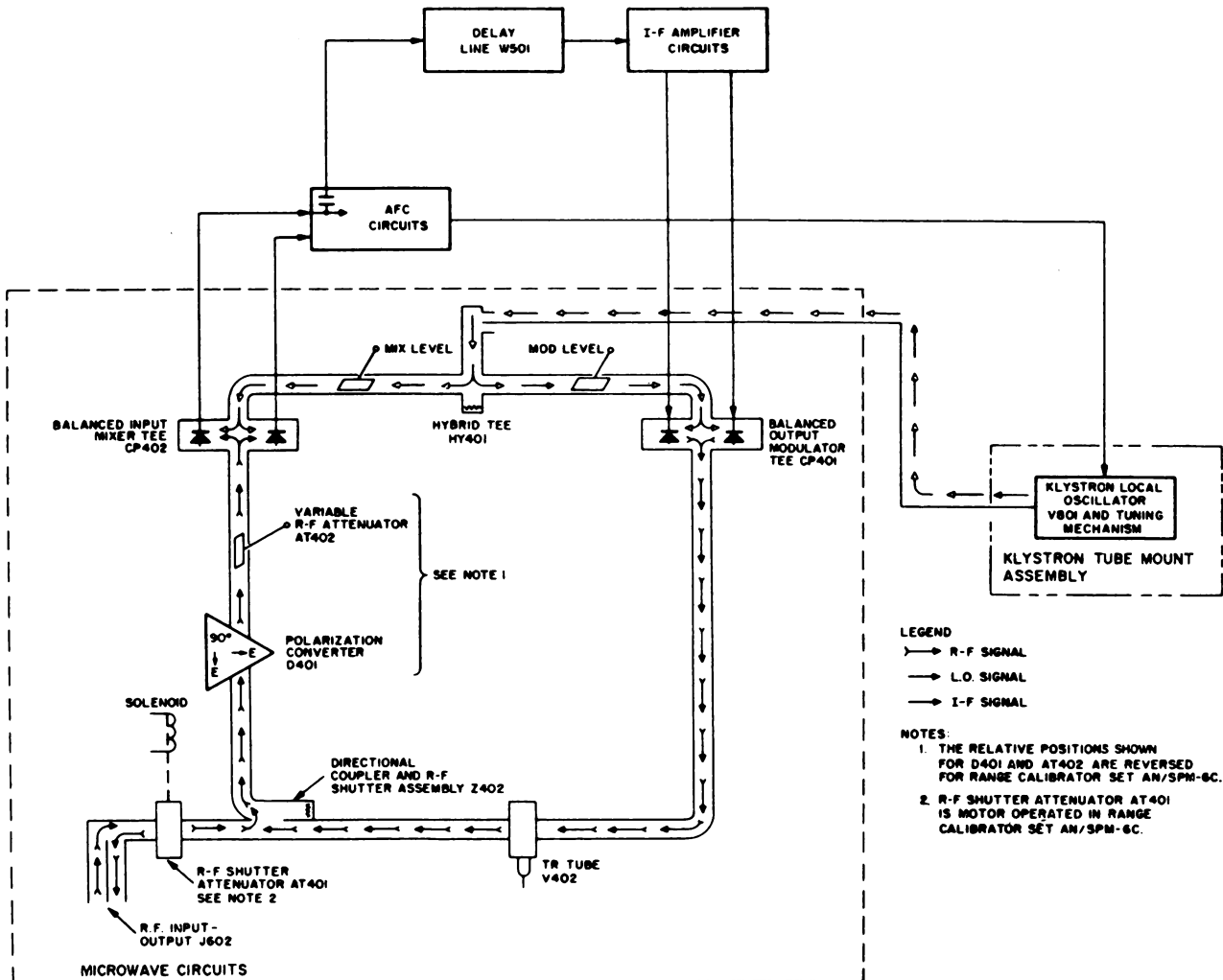
When the first mechanical excitation reaches the output end of the rod, it is transformed into an electrical impulse by a second piezoelectrical crystal attached to the end face. In addition, the first mechanical impulse is reflected back toward the input end of the rod. A reflection occurs each time a pulse is incident upon an end face, thus producing a train of gradually attenuated output pulses for a single input pulse. The delay between the second and third pulses, the third and fourth pulses, and the like, is twice the delay of the quartz rod since all output pulses following the first pulse traverse the rod back and forth. The train of

i-f pulses at the output end of the delay line are fed to the i-f amplifier, where, because of attenuation in the quartz rod delay line, the i-f train must be amplified prior to going to the modulator.

The fused quartz is enclosed by a heater which is thermostatically controlled to maintain the rod temperature at 71° C. This results in the delay line having a constant delay.

PREOPERATIONAL PROCEDURES

The range calibrator set can introduce its pulses to the radar either through air coupling between the radar antenna and range calibrator set, or direct coupling from the range calibrator set to the radar transmission line. The procedures required to prepare for those coupling methods are detailed in the following paragraphs.



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Figure 13-36. —R-f transponder loop signal flow block diagram.

Preparation For Air Coupling

To prepare for the air coupling method of checking range indicator accuracy of a radar set, perform the following steps:

1. Connect r-f cable assembly CG-92A/U (fig. 13-38), between the pickup horn assembly and the r-f input-output receptacle on the range calibrator set. The cable assembly CG-92A/U and the pickup horn assembly are both located in the carrying case cover.

2. Place the pickup horn assembly (fig. 13-38), in front of and pointing toward the radar antenna. Since the radar is at zero range for this method of coupling, it is necessary to measure the distance from the radar antenna to the pickup horn.

Preparation For Direct Coupling

When it is impractical to place the range calibrator set near the radar antenna for air coupling, prepare for direct coupling to the radar set. To direct couple, place the range calibrator set in a convenient position and connect r-f cable assembly CG-92A/U (fig. 13-39) between the r-f input-output receptacle on the calibrator set and the directional coupler in the radar transmission line.

RADAR RANGE COMPUTATIONS

To check the range accuracy of the radar set under test, it is necessary to compute the

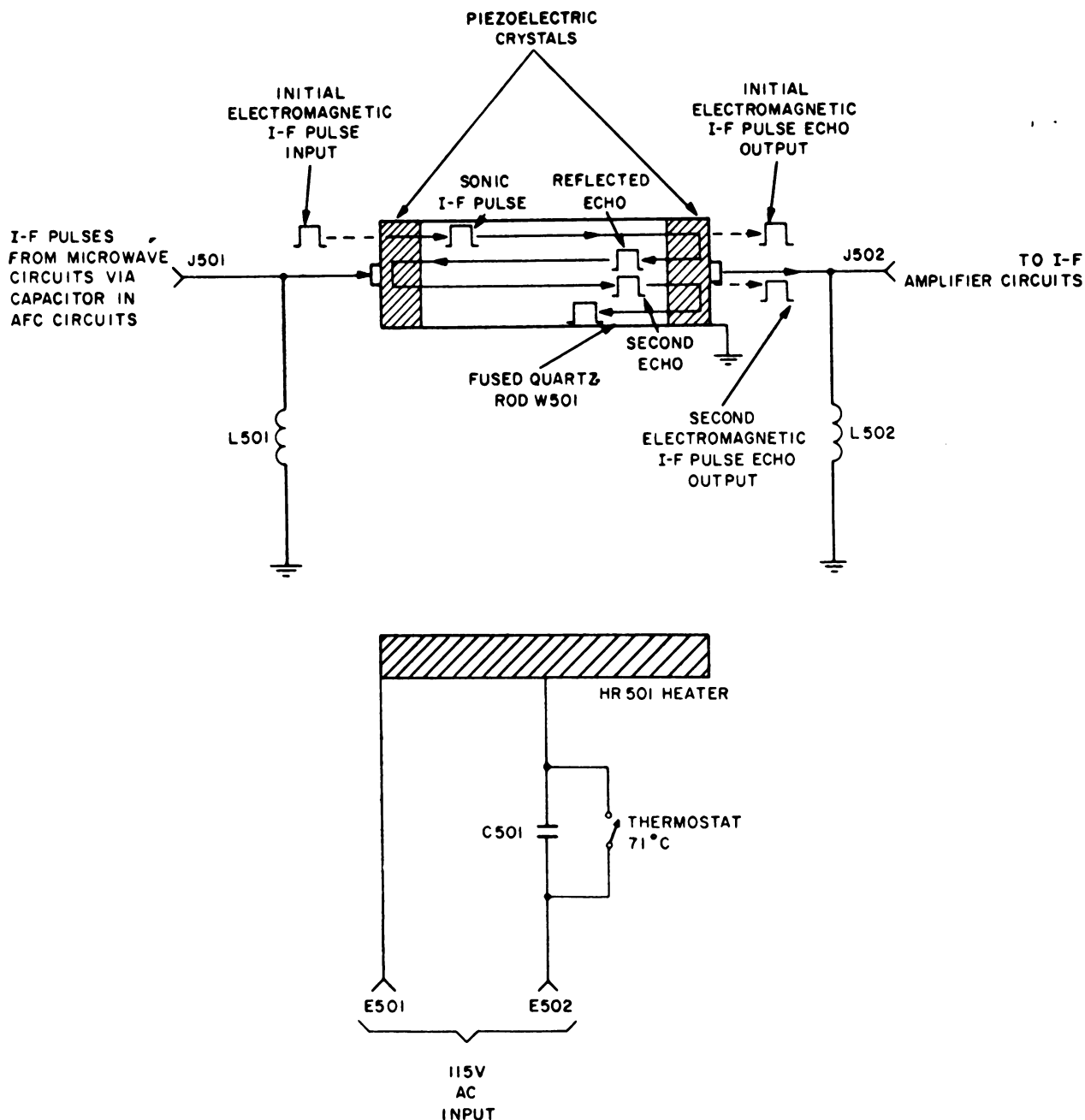


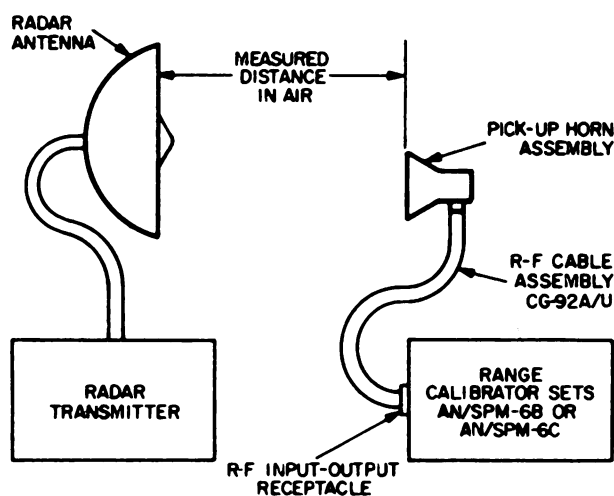
Figure 13-37. —Delay line, simplified schematic.

92.150

radar range of the pulses in the pulse train developed at the range calibrator set output. In the following paragraphs, procedures are presented for computing the radar range of the echoes using both the air coupling and direct coupling methods of connecting to the external

source under test. A paragraph is also included to describe the procedure for determining the delay of the transmission line used in the range computation.

NOTE: The internal delay of the range calibrator set, which includes the delay of



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Figure 13-38.—Air coupling method of operation.

the i-f amplifier assembly and the internal cables, is marked on a tag on the i-f amplifier assembly. The delay of the delay line is marked on the delay line oven assembly.

Computations Using Air Coupling Data

If the air coupling method is used, total the radar range equivalents of the following:

1. Distance between the radar antenna and the pickup horn assembly.
2. Internal delay of the range calibrator set, less the delay of the delay line.
3. Delay of the r-f cable between the range calibrator set and the pickup horn assembly. This delay is considered negligible if it is less than three yards.
4. Delay of the delay line.

The sum of these four represents the radar range of the first pulse. The range indication at the second pulse is the sum of two delays, the delay to the first echo pulse plus twice the delay of the delay line.

Example:

Distance between radar antenna and pickup horn is 50 yards.

Internal delay of range calibrator set (typical value) is 20 yards.

Delay of the r-f cable is 10 yards.

Delay of the delay line is 1800 yards.

Radar range of first pulse is $50 + 20 + 10 + 1800 = 1880$ yards.

Radar range of second pulse is $50 + 20 + 10 + 1800 + 2(1800) = 5480$ yards.

Radar range of Nth pulse is equal to $D_F + D_C + D_A + D_L + 2D_L(N-1)$.

D_F = the free-space distance between the radar antenna and the pickup horn assembly.

D_C = the internal delay of the range calibrator set, less the delay of the delay line.

D_A = the delay of the r-f cable between the range calibrator set and the pickup horn assembly.

D_L = the delay of the delay line.

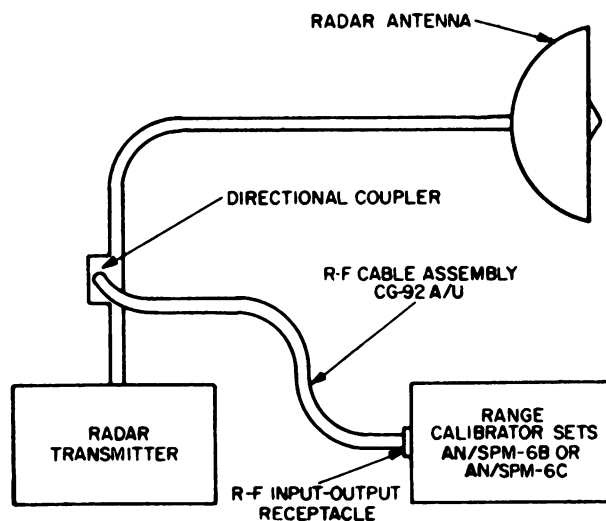
N = the number of the pulse being used in the computation.

NOTE: An A-scope presentation of the preceding example would appear as shown in figure 13-40.

Computations Using Direct Coupling Data

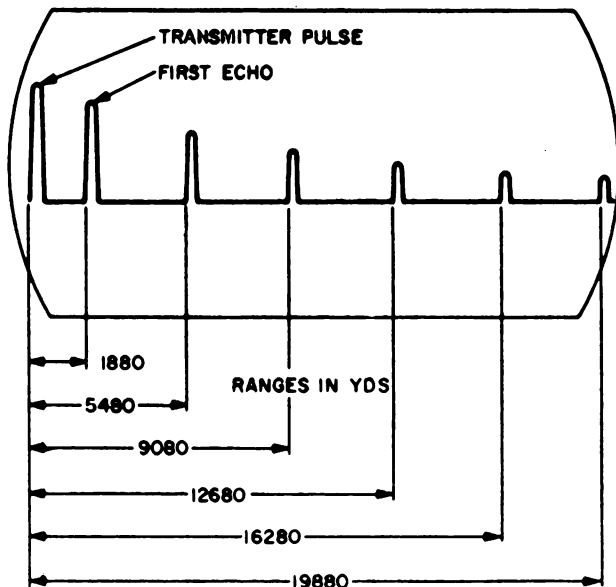
If the direct coupling method is used, three slightly different computations exist. In each computation, the transmission line refers to the radar transmission line between the directional coupler and the radar antenna.

For the first computation, it is assumed that the transmission line is of negligible length, that is, less than 5 yards equivalent radar range, and that the same holds true for the length of r-f cable between the directional



92.152

Figure 13-39.—Direct coupling method of operation.



92.153

Figure 13-40. —Using delayed pulses for checking radar range accuracy (with 1800-yard delay line).

coupler and the range calibrator set. For this case, the calculated delay to the first pulse of the range calibrator set is the sum of the internal delay of the calibrator set and the delay of the delay line.

For the second computation, the assumption that the transmission line is of negligible length still holds true, but the length of the r-f cable connecting the range calibrator set to the radar set is of appreciable length. Therefore, the radar range to the first pulse is the sum of the delays in the delay line, the r-f cable, and the internal delay of the range calibrator set.

The third computation of range arises when the r-f cable connecting the range calibrator set to the radar set is of appreciable length, and the transmission line to the radar antenna is long and inaccessible, although the transmission line delay is known. Then, the delay of the delay line, the internal delay of the range calibrator set, and the delay of the r-f cable are added, and the delay of the antenna transmission line is subtracted. The transmission line delay is subtracted to place zero range at the antenna.

Example:

Delay of r-f cable to range calibrator set is 10 yards.

Internal delay of range calibrator set is 20 yards.

Delay of the delay line is 1800 yards.

Delay of antenna transmission line is -30 yards.

Radar range of the first pulse is $10 + 20 + 1800 - 30 = 1800$ yards.

Radar range of second pulse is $1800 + 2(1800) = 5400$ yards.

Radar range of Nth pulse = Radar range of first pulse + $2D_L(N-1)$.

Again, D_L = the delay of the delay line.

For this example, the radar range dial indication at the first pulse should be 1800 yards and the radar range dial indication to the second pulse should be 5400 yards.

DETERMINING TRANSMISSION LINE DELAY

It was assumed for computation in the previous paragraph that the transmission line delay was known. If the transmission line delay is not known, as might be the case for a recently installed radar set, the range calibrator set can be used in its secondary function to determine this delay as follows.

1. Calibrate or check the radar range circuits using the air coupling method. However, it is convenient to reference the range of the antenna by subtracting both the r-f cable delay and the distance in air between the antenna and the pickup horn assembly. This has the same effect as placing the range calibrator set at the radar antenna.

2. Make a direct coupling to a directional coupler as near to the radar set receiver as possible. Here, it is convenient to reference the range indication to the directional coupler by subtracting the delay of the r-f cable leading to the range calibrator set. This subtraction will have the effect of placing the range calibrator set at the directional coupler.

3. Since the two reference figures arrived at were based on placing the range calibrator set at the antenna and at the directional coupler, respectively, any difference between the reference figures must be a result of the delay in the transmission line.

The following paragraphs describe how data collected from the air coupling and direct coupling methods of range calibrator set operation are used to calculate the transmission line delay.

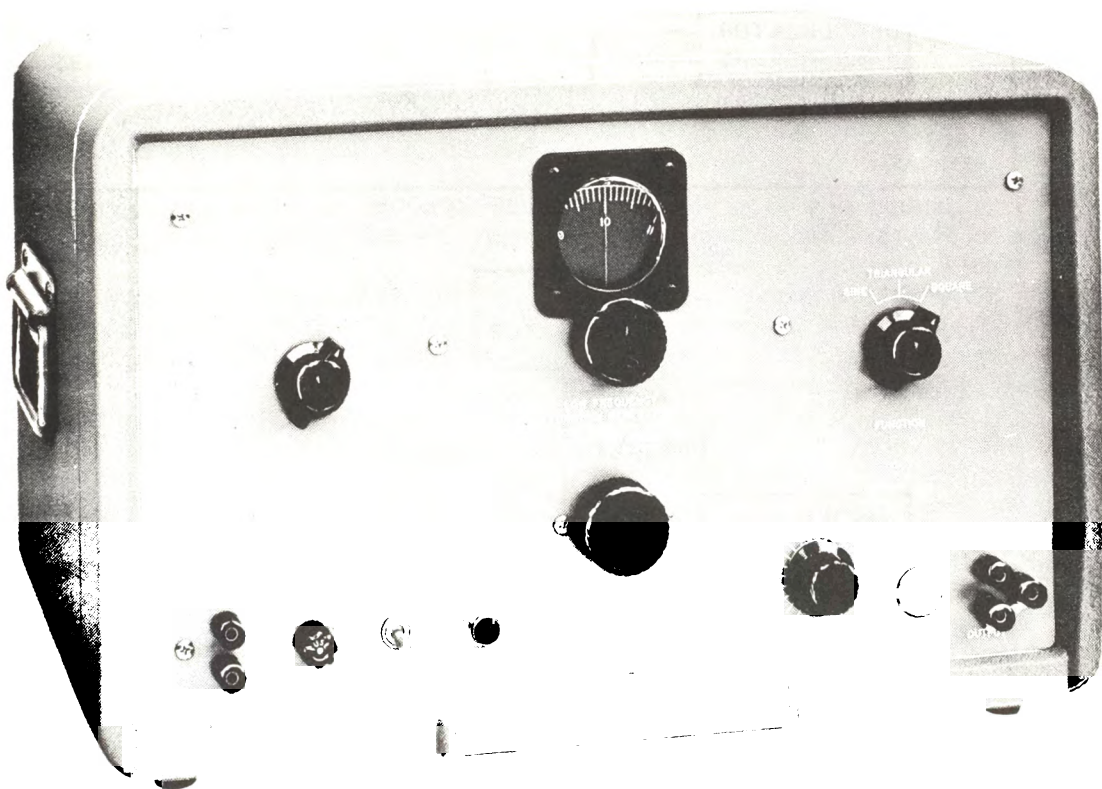


Figure 13-41.—Low frequency function generator HP Model 202A

92.154

Air Coupling Data

In the previous example for coupling data, the range calibrator set pickup horn assembly was 50 yards from the radar antenna, and a cable with a 10-yard delay connected the range calibrator set to the pickup horn assembly. The internal delay of the range calibrator set was 20 yards, and the delay of the delay line was 1800 yards. From this data it was found, in the calculations, that the first echo was delayed an equivalent radar range of 1880 yards. The radar set should be calibrated to this value.

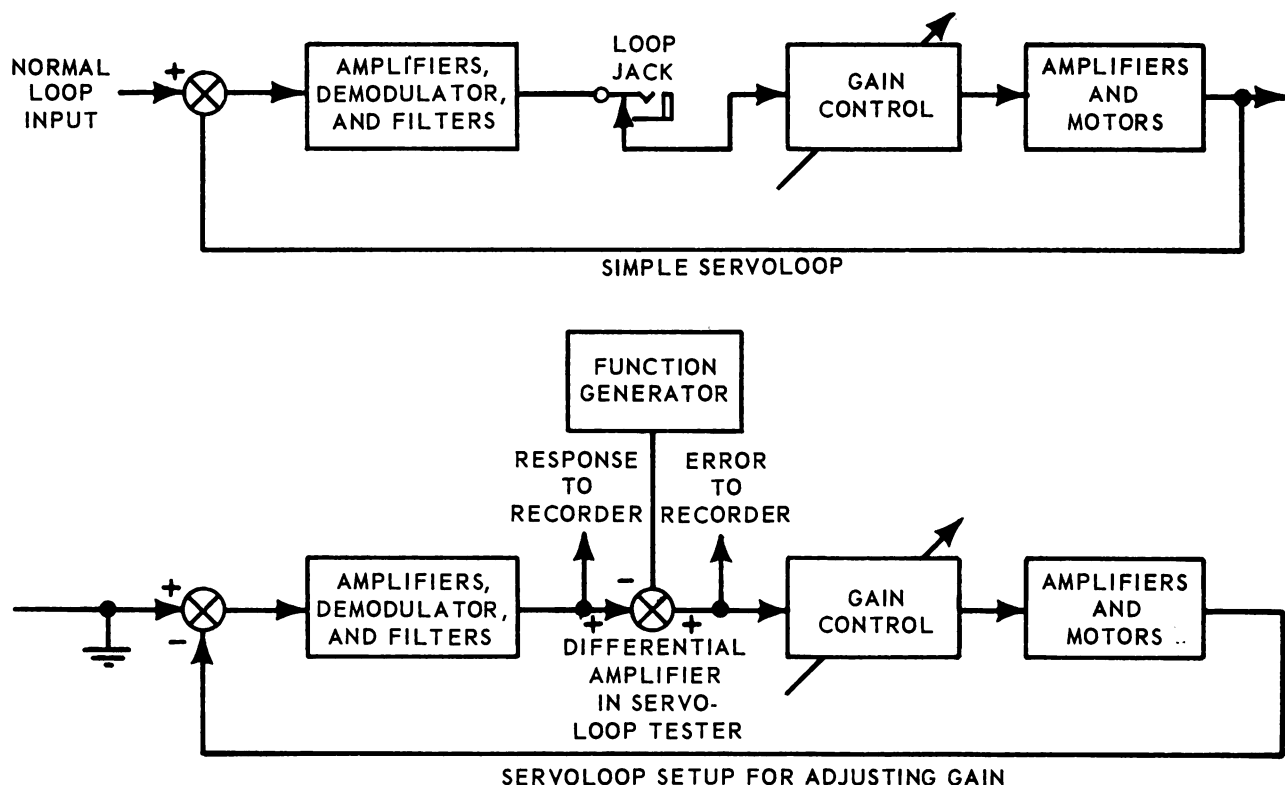
To reference the range calibrator set to the radar antenna, subtract from the total delay the 50-yard distance between the radar antenna and the pickup horn assembly, and the 10-yard delay of the r-f cable between the range calibrator set and the pickup horn assembly.

$1880 - 60 = 1820$ yards delay to the first echo pulse with range calibrator set referenced to the radar antenna.

Direct Coupling Data

In the previous example for direct coupling data, the delay of the r-f cable between the range calibrator set and the directional coupler was 10 yards, and the range calibrator set internal delay was 20 yards. The delay of the delay line was 1800 yards and the transmission line delay unknown.

In this application the delay of the first echo, as read from the radar ranging circuits, is 1800 yards. To reference the range calibrator set to the directional coupler, subtract the 10-yard delay of the r-f cable connecting the range calibrator set and the directional coupler.



92.155

Figure 13-42. —Servoloop setup for adjusting gain.

1880 - 10 = 1790 yards delay to the first echo pulse with the range calibrator set referenced to the directional coupler.

Calculating Transmission Line Delay

With the range calibrator set referenced to the radar antenna, the delay of the first pulse was found to be 1820 yards; and with the range calibrator set referenced to the directional coupler, the delay of the first pulse was found to be 1790 yards. Therefore, the difference between these delays (1820 - 1790 = 30 yards) represents the delay of the radar transmission line.

RADAR SYSTEMS WITH SLOPE ADJUSTMENTS

In some radar systems, a slope adjustment is incorporated in the ranging circuits. For these systems, the range indicator may be correct at one point but incorrect at all other

points because of improper setting of the slope control. It is necessary to check such systems at two points, correcting the range indications with the slope control for the second point. For accuracy, the two echo pulses used should be as far apart as practical.

SUMMARY OF OPERATION

The following procedure summarizes the steps required to use the calibrator to check the range accuracy of the radar set under test.

1. Arrange the range calibrator set, for convenient operation.
2. Remove the carrying case cover.
3. Connect the set to a 115-volt single-phase 50- to 1000-cps power source, and apply power.
4. If air coupling is to be used as shown in figure 13-38, measure the distance from the antenna to the pickup horn.
5. If direct coupling is to be used as shown in figure 13-39, connect the range calibrator

set to a directional coupler in the radar transmission line.

6. Place the ON-OFF switch to ON.
7. Rotate the R-F ATTENUATOR control fully counterclockwise.
8. Place the SWEEP-MANUAL-AFC switch at MANUAL, and center the SIGNAL LEVEL meter pointer using the METER CENTERING adjustment.
9. Check crystal currents of mixer and modulator tees for readings of 0.6 ± 0.1 milliamperes.
10. Turn SWEEP-MANUAL-AFC switch to SWEEP.
11. Apply pulsed microwave power to the set.
12. Adjust the L.O. TUNING control completely counterclockwise, and then turn it clockwise for two dips on the SIGNAL LEVEL meter.
13. If no dip appears, decrease the R-F ATTENUATOR setting (by turning clockwise) about one-quarter of its travel and repeat step 12.
14. At the second dip, turn the L.O. TUNING control counterclockwise and set it at the first dip. Maximize the dip.
15. Place SWEEP-MANUAL-AFC switch at MANUAL.
16. Recheck the crystal currents of the mixer and modulator tees.
17. Rotate the L.O. REP control until the SIGNAL LEVEL meter pointer is at midscale between the negative and positive points of travel.
18. Place the SWEEP-MANUAL-AFC switch at AFC.
19. Measure the mixer and modulator crystal currents.
20. Optimize the afc lock-on.
21. The calibrator is now at optimum performance, therefore, the appearance of the pulses on the radar range scope may be used to check radar range accuracy. Total the delays

for the range to the first echo pulse, and add to that total twice the delay line delay value for the range to the second pulse.

22. Turn the test set off by placing the ON-OFF switch at OFF.

LOW FREQUENCY FUNCTION GENERATOR

A piece of test equipment currently being used for checking the gain of servoamplifiers is the low Frequency Function Generator, Hewlett-Packard Model 202A (fig. 13-41). It is a convenient source of transient-free voltages with a frequency range of .008 to 1200 cps. It has three types of waveforms available; sine, square, and triangular.

Since correct gain of the servoloop is necessary for the proper performance of the loop, a gain control potentiometer is provided in all loops for adjustment of the gain. Most servoloops are wired to allow the loops to be "broken into" in order to facilitate the adjustment of the gain potentiometers. In the newer systems this is accomplished by inserting a servoloop tester containing a differential amplifier into the system. In the test setup (fig. 13-42), the response signal is one input of the differential amplifier. The other input is obtained from the low frequency function generator which supplies a voltage of a desired frequency and amplitude. The difference between the two inputs is present at the amplifier output, which is then routed back to the loop input to complete the closure. Thus the differential amplifier is connected in series within the loop, and a method is thereby provided to introduce the signal from the function generator and to monitor the error and response of the loop. By using a sine wave at a frequency at which the loop is designed to have unity gain, the gain control potentiometer can be adjusted for equal amplitudes of error and response.

APPENDIX I

TRAINING FILM LIST

Chapter 3

ANALOG COMPUTERS

- SN-1811A The Computer, Mark 1, Introduction—Part 1—Rates.
(17 min.—97 frames—B & W—Sound—Unclassified—1945.)
Uses schematic drawings to drive the computer into functional groups to study theory and operation. Explains computation of gun order, corrections, predictions, and rates. Discusses principles of tracking.
- SN-1811B The Computer, Mark 1, Introduction—Part 2—Rate Control.
(18 min.—98 frames—Sound—Unclassified—1945.) Describes methods of rate control: semi-automatic, in which rate-operators do the job; automatic, in which director-operators are in control; and manual, used for surface targets only.
- SN-1811C The Computer, Mark 1—Introduction—Part 3—Predictions and Orders. (17 min.—95 frames—B & W—Sound—Unclassified—1945.) Explains how rates are used by the prediction group (wind rates, advance range and fuze values, sight deflection and angle group), trunnion tilt, and parallax units to produce gun orders.
- MN-7317A The Computer Mark 1A—The Mark 37 System and Tracking the Target. (22 min.—B & W—Sound—Unclassified—1952.) This film gives an outline of the complete system: the relationship of computer, director, guns and auxiliary equipment, gyro compass and pitometer log, the duties of control officer, trainer, pointer and range operator; definitions of line of sight, line of fire, director elevation and director train; the necessity for gun lead angles; the definitions of and dials for ship's course, ship's speed, relative target bearing, observed range, target angle, rate of climb and horizontal target speed; solution indicators; trainer, pointer and range operator signals; relative motion rates; generated rates of target motion; rate control.

- MN-7317B The Computer Mark 1A—Establishing the Line of Fire. (7 min.—B & W—Sound—Unclassified—1952.) This film shows the necessity for predicting future target position; the definitions of the counters for sight deflection, sight angle and fuze time; setting in wind corrections for wind speed and wind direction; the definitions of initial velocity and deadtime; setting in ballistic corrections for initial velocity and dead time; modification of values of director train and director elevation by lead angles to produce gun orders.
- MN-7317C The Computer Mark 1A—A Sample Problem. (7 min.—B & W—Sound—Unclassified—1952.) This film shows a sample fire-control problem; how action above deck can be visualized at the computer; picking up target; beginning of tracking; rate controlling; technique of use and interpretation of trainer, pointer and range finder operator signals; changes in range, elevation and bearing as problem progresses; reaching the solution; values of horizontal target speed, rate of climb and target angle at moment of solution.
- MN-7317D The Computer Mark 1A—Stabilization. (12 min.—B & W—Sound—Unclassified—1952.) Movement of director and guns caused by roll and pitch; necessity for holding line of sight and line of fire independent of roll and pitch; definition of stabilization; definition of level and cross-level; function of stable element; stabilization of director sights in elevation and bearing; stabilizing the line of sight; stabilization of director elevation and observed bearing for use by the computer; definition of deck-tilt correction; stabilization of line of fire production of gun orders.

Chapter 4

WEAPONS CONTROL SYSTEM

- SN-1595A The Mark 37 Gun Director—Description of the System—Part 1. (18 min.—122 frames—B & W—Sound—Unclassified—1943.) Explains fire control system, master key fire, location and relation of the Mark 37 director, Mark 6 stable element, Mark 1 computer, guns, and searchlights.
- SN-1595B The Mark 37 Gun Director—Description of the System—Part 2. (10 min.—66 frames—B & W—Sound—Unclassified—1943.) Explains duties of the control officer and assistant, trainer, pointer, range finder operator and assistant, and illumination control officer when the target is sighted.

- SN-1801E The Stable Element, Mark 6—How the Outputs are Driven. (15 min.—74 frames—B & W—Sound—Unclassified—1944.) Explains basic gearing of the stable element and how its outputs are driven.
- MN-7317E The Computer Mark 1A—The Star Shell Computer. (6 min.—B & W—Sound—Unclassified—1952.) Function of star shells; comparison of Computer Mark 1A with Star Shell Computer Mark 1; production of orders for guns firing star shells; definition of star shell range; star shell elevation prediction; settings with range shell gun elevation order and star shell gun train order.
- MN-8343A Target Designation System, Mark VI—Target Designation in Air Defense. (9 min.—B & W—Sound—Unclassified—1958.) This film is intended for showing as an introduction to the target designation problem. The five basic steps of designation are discussed: search, identification, evaluation, designation, and acquisition. The need for fast and accurate designation against the high-speed aircraft of today is emphasized.
- MN-8634 Gun Fire Control System, Mk 37. (14 min.—B & W—Sound—Unclassified—1958.) This film describes the Mk 37 Gunfire Control System, its capabilities, components, and the functional relationship of the components. It should be used as a point of departure for the study of any of the individual components.
- SN-1801A The Stable Element, Mark 6—The Purpose of the Stable Element. (11 min.—64 frames—B & W—Sound—Unclassified—1943.) Explains how level and cross-level are transmitted, and how the optics respond. Discusses trim and elevation.
- MN-7317A The Computer Mark 1A—The Mark 37 System and Tracking the Target. (22 min.—B & W—Sound—Unclassified—1952.) This film gives an outline of the complete system: the relationship of computer, director, guns and auxiliary equipment, gyro compass and pitometer log, the duties of control officer, trainer, pointer, and range operator; definitions of line of sight, line of fire, director elevation, and director train; the necessity for gun lead angles; the definitions of the dials for ship's course, ship's speed, relative target bearings, observed range, target angle, rate of climb and horizontal target speed; solution indicators; trainer, pointer, and range operator signals; relative motion rates; generated rates of target motion; rate control.

Chapter 6

BATTERY ALIGNMENT

- SN-1808A Battery Alignment—Program of Gun and Gun-Sight Alignment. (20 min.—127 frames—B & W—Sound—Unclassified—1944.) Shows the three requirements for a correctly aligned gun: trunnion axis parallel to trunnion axis; line-of-sight and bore center-line converged at mean battle range. Shows why these are important and the results which occur if these conditions are not met.
- SN-1808B Battery Alignment—Alignment of Gun and Mount. (25 min.—110 frames—B & W—Sound—Unclassified—1944.) Preliminary check of the mount is briefly explained. Theory of checking alignment of the trunnion and roller path is demonstrated in detail. Demonstrates transit and plumb-line tests for trunnion alignment. Explains and demonstrates test for alignment of gun barrels in multiple-mounts.
- SN-1808C Battery Alignment—Alignment of Sights with Gun and Mount. (23 min.—110 frames—B & W—Sound—Unclassified—1944.) Preliminary checks for deflection and lost motion. Procedure in tests for alignment of yoke and carriage-type sights. Misalignment of sights must be reported to Navy Yard for adjustment procedures.
- SN-1808D Battery Alignment—Boresight Telescope and Boresighting. (30 min.—89 frames—B & W—Sound—Unclassified—1944.) Muzzle disk and telescope are installed, the latter with the boresight telescope adapter. Telescope line-of-sight is then aligned with the peep-hole. Check for optical errors such as parallax and incorrect collimation. Procedure of boresighting, including preliminary checks, are also covered.
- SN-1808E Battery Alignment—Alignment of the Installation in Drydock—Train. (22 min.—86 frames—B & W—Sound—Unclassified—1944.) Transmission check from the director to one of the guns is demonstrated; aligning the battery in-train is followed step-by-step. Explains establishing the center of rotation of an element by two methods.
- SN-1808F Battery Alignment—Alignment of the Installation in Drydock—Elevation—Part 1. (11 min.—27 frames—B & W—Sound—Unclassified—1944.) Determination of roller-path inclinations of director and gun in drydock is covered. Illustrates selecting the reference-plane and outlines, briefly, manner of determining inclination of the director roller-path and each roller-path with respect to the reference plane.

- SN-1808G Battery Alignment—Alignment of Installation in Drydock—Elevation—Part 2. (15 min.—62 frames—B & W—Sound—Unclassified—1944.) Setting director and gun deals to read zero elevation relative to the respective roller-paths, obtaining benchmarks and tram records; setting and roller-path correctors are demonstrated and explained in detail.
- SN-1808H Battery Alignment—Alignment of the Installation Afloat—Train—Part 1. (20 min.—80 frames—B & W—Sound—Unclassified—1944.) Explains parallax, both director and gun, and shows that in case of directors, maximum parallax exists when a target is on the beam and zero parallax exists for targets dead-ahead or dead-astern. Explains use of a reference point or of making one director the reference. Gun parallax exists between directors and gun, and the gun can set in correction in its own mechanism. Shows how to check direction of parallax and amount of parallax (unit parallax based on a 100-yard line from the reference point).
- SN-1808I Battery Alignment—Alignment of the Installation Afloat—Train—Part 2. (17 min.—64 frames—B & W—Sound—Unclassified—1944.) Describes the following operations: checking the director on benchmarks evaluation; in train with and without the parallax mechanism; aligning the guns with the director; preliminary train test; complete train test; train check with the sights set.
- SN-1808J Battery Alignment—Alignment of the Installation Afloat—Elevation. (14 min.—74 frames—B & W—Sound—Unclassified—1944.) Explains purposes and procedures of re-setting roller-path tilt-correctors when a ship is afloat. Demonstrates simple elevation check, and checking the gun response in automatic.

Chapter 7

SPOTTING AND NAVAL GUNFIRE SUPPORT

- MN-6556E Amphibious Warfare Instructions—Naval Gunfire Support Part 1. (14 min.—B & W—Sound—Confidential—1948.) Description of this film is classified and can be found in United States Navy Film Catalog, NavPers 10001-A.
- MN-6556F Amphibious Warfare Instructions—Naval Gunfire Support—Part 2. (20 min.—B & W—Sound—Confidential—1949.) Description of this film is classified and can be found in United States Navy Film Catalog, NavPers 10001-A.
- MN-4315 Amphibious Warfare—Shore Fire Control Party. (16 min.—B & W—Sound—Confidential—1944.) Description of this film is classified and can be found in United States Navy Film Catalog, NavPers 10001-A.

Chapter 9

MICROWAVE COMPONENTS

- MN-8814F Special Circuits and Devices Klystron—Power Amplifiers. (9 min.—B & W—Sound—.) Pictorial flow diagram of klystron power amplifier.
- MN-8814B Cavity Resonators. (8 min.—B & W—Sound—Unclassified—1959.) Brief theory of the action of energy in a cavity resonator.
- MN-8814A Special Circuits and Device—Waveguides. (18 min.—B & W—Sound.) Presents a brief theory of propagation of energy down a waveguide.

Chapter 10

RADAR ANTENNAS

- MA-1704 Radio Antennas—Creation and Behavior of Radio Waves. (11 min.—B & W—Sound—Unclassified—1942.) Demonstrates how electromagnetic fields are formed and illustrates behavior of sky and ground radio waves.
- MV-9329A Radio Antenna Fundamentals—Part 1. (27 min.—B & W—Sound—Unclassified—1952.) USAF TF 14801. Photography and animated charts describe radio transmission system. Cycle of wavelength is followed and standing wave is described along with other radio antenna reception components.
- MN-9329B Radio Antenna Fundamentals—Part 2. (16 min.—B & W—Sound—Unclassified—1952.) Radio transmission system in ground and air operations. Nondirectional radiation and various antennas are discussed.
- MN-5050A Radar—Accuracy and Resolution—Range. (10 min.—B & W—Sound—Unclassified—1946.) How to obtain accurate ranges from various types of radar, especially when targets are merged or nearly so. Technique of calibration, expanded scope, and reduced gain is explained. Explains range resolution.
- MN-5050B Radar—Accuracy and Resolution—Bearing. (16 min.—B & W—Sound—Unclassified—1946.) How to get accurate bearings with various types of gear. Describes and explains lobe, effective beam width, excitation level, maximum and minimum methods of attaining bearing, and use of gain in improving accuracy.

Chapter 11

ADMINISTRATION

- MN-6753A Training Aids—Selection and Planning. (16 min.—B & W—Sound—Unclassified—1950.) Shows how the Navy Instructor selects and plans for the use of training aids. With lesson plan as a starting point, he determines where and how training aids will help him most in teaching the day's lesson. He gives careful consideration to advantages of the motion picture, still picture, chart, model, and mockup in planning for this lesson. Finally, he checks classroom, training aids he has selected, and projection equipment to make sure his presentation of the lesson will proceed smoothly and efficiently.
- MN-6753B Training Aids—Classroom Utilization. (15 min.—B & W—Sound—Unclassified—1950.) Instructor, having selected his training aids and planned for their use in terms of the lesson plan, is now ready to use training aids in the classroom. Follows a good instructor through a complete class lesson to illustrate proper utilization of Navy training aids. Use of several types of aids to teach the lesson and student participation with training aids is described in detail.
- MN-6753C Training Aids—Slides, Large Drawings and Transparencies. (17 min.—B & W—Sound—Unclassified—1951.) Film urges instructors to make their own 3 1/4" x 4" lantern slides, large drawings and large transparencies used with the overhead projector. Gives an indication of the equipment, materials, and opportunities for training aid preparation available to every naval instructor.
- MN-6947 Security Control—You Never Can Tell. (36 min.—B & W—Sound—Unclassified—1952.) Teaches security by following a Naval Security Officer through the offices, laboratory and production plant of manufacturer producing a classified device for the Navy. The Security Officer, in search of information leaks which caused the device to be ineffective during a Naval engagement, discovers and points out existing conditions which would enable an espionage agent to operate in the factory.
- FN-9433A Principles of Paperwork Management. (13 min.—Color—Sound—Unclassified—1960.) A presentation that describes the qualities of efficient, effective letter-writing and suggests ways of obtaining these qualities.
- FN-9433D Principles of Paperwork Management—Managing Your Forms. (17 min.—Color—Sound—Unclassified—1960.) This film describes the efficient design and use of Navy forms and shows common errors. The procedure for obtaining well-designed forms is outlined.

- FN-9433E** Principles of Paperwork Management—Managing Your Reports. (11 min.—Color—Sound—Unclassified—1961.) Describes common deficiencies which occur in reports and in reporting procedures. Describes areas of possible improvement such as quality of content, frequency and timing, preparation procedures, and cost.
- FN-9433F** Principles of Paperwork Management—Records Disposal. (15 min.—Color—Sound—Unclassified—1961.) Calls attention to the records disposal problem and suggests ways of solving it. Describes office management techniques for obtaining efficient use of records storage space and for obtaining correct and timely records disposal action. Introduces and briefly describes relevant Navy manuals.

Chapter 12

SUPPLY

- MN-9460** The Supply Manager's Dilemma. (19 min.—Color—Sound—Unclassified—1960.) This is an introductory film which describes the influence of order costs, holding costs, shortages, and other factors in determining supply management policies.
- MN-9464** Supply Overhaul. (17 min.—B & W—Sound—Unclassified—1960.) This film explains the need for increased supply endurance for the ships in the U. S. Navy and shows the supply overhaul process of purifying afloat inventories to achieve increased endurance. It also depicts the importance of positive shipboard equipment validation and covers the vital parts played by fleet and ashore personnel in the purification of shipboard material and records.
- MA-9676** Classes of Supply. (10 min.—B & W—Sound—Unclassified—1961.) U. S. Army TF10-3093. This film defines the five classes of supply, outlining the various items within those classes, and the representative class symbols.
- FN-8552A** Popularity Storage—Principles of Stock Positioning. (18 min.—Color—Sound—Unclassified—1958.) Illustrates the four basic principles of "Popularity Storage", namely; demand, similarity, size and characteristics. Describes the benefits to be derived from the application of these principles in stock positioning at all levels of the supply system.
- FN-8552B** Popularity Storage—Planning the Storage Layout. (20 min.—Color—Sound—Unclassified—1958.) The film describes completely all phases of storage space layout, control of space, material positioning, design of stock location

system, and stock location as it implements the new storage program.

- FN-8801 Coordinated Shipboard Allowance List. (19 min.—B & W—Sound—Unclassified—1959.) Shows how COSAL publications are employed by technical and supply personnel aboard ship, to avoid overlapping and duplication of stored parts and equipment, and maintain well balanced stocks for self support. How to use the lists is covered in detail.
- MN-7946 Importance of Military Packaging. (8 min.—B & W—Sound—Unclassified—1953.) A photographic report designed to motivate suppliers to adhere to military packaging specifications. Illustrates the wide differences between military and civilian supply routes; shows typical material handling from stateside to hostile beach; illustrates waste and loss of machinery, parts, clothing and foodstuffs from inadequate packaging, and shows that packaging according to proven military requirements will deliver material in usable condition.

Chapter 12

WEAPONS DIRECTION SYSTEM COMPONENTS

- MN-8342A Target Designation System, Mark VI—Target Designation in Air Defense. (9 min.—B & W—Sound—Unclassified—1958.) This film is intended for showing as an introduction to the target designation problem. The five basic steps of designation are discussed: search, identification, evaluation, designation, and acquisition. The need for fast and accurate designation against the high-speed aircraft of today is emphasized.
- MN-8342F Target Designation System, Mark VI—Symbol Generation. (15 min.—B & W—Sound—Unclassified—1958.) This film describes the origin of presentation symbols (director numerals and designator symbols) as seen on the indicator. This film also explains how this presentation is oriented with respect to own ship.
- MN-8342G Target Designation System, Mark VI—TV Synchronizing Circuits. (17 min.—B & W—Sound—Unclassified—1959.) This film shows the basic operation of the circuits employed in a closed circuit TV for generation of TV drive and blanking pulses.
- MN-8342H Target Designation System, Mark VI—TV Deflection Circuits. (21 min.—B & W—Sound—Unclassified—1959.) This film explains the basic circuitry and principles of operation of TV Horizontal and Vertical deflection

circuits. Simple adjustments are presented and their results illustrated. It is applicable to deflection circuits in both military and commercial TV systems.

APPENDIX II

SAFETY PRECAUTIONS

The following are general safety precautions. These precautions are recommended safety precautions that maintenance personnel must understand and apply in addition to those laid down in Chapter 67 of Bureau Of Ships Technical Manual NavShips 250,000, including the latest changes.

1. High Voltages, dangerous to life, may be met during maintenance procedures. Use extreme caution when working in areas where high voltages are present.

2. RADIATION. Both X and Microwave radiations, which could be dangerous to health, may be present near radar transmitters. Use suitable detection instruments to determine the presence of radiation. Personnel assigned to work in the vicinity of radiation sources should wear radiation indicators to determine amount of exposure.

3. The radiological officer should be consulted for the latest data on the effects of both X and Microwave radiation on the human body.

4. The chart on page 319 shows the hazard zones for the C-band, X-band and combined bands of modern radars.

5. When it is necessary to perform maintenance on radars with power radiating from the antennas, take the necessary steps to keep the antennas directed into open areas whenever possible.

6. Personnel working in the vicinity of radiation sources should perform their duties in the shortest time possible.

7. Do Not work alone. Make certain that at least one other person is prepared to open the circuits that are being tested.

8. Never measure voltages in excess of 1000 volts by means of flexible leads or probes.

9. Make sure you are not grounded whenever you are adjusting equipment or using measuring equipment.

10. Use one hand only when servicing live equipment.

11. Do Not wear rings, wristwatches, bracelets, and similar metal items while working around electronic equipment.

12. If test meter must be held or adjusted while voltage is applied, ground the case of the meter before starting equipment, and do not touch live equipment or personnel working on live equipment while you are holding the meter. Some moving vane type meters should not be grounded during measurement.

13. High Voltages may be present across terminals that are normally low voltage, due to equipment breakdown. Be Careful even when measuring low voltages.

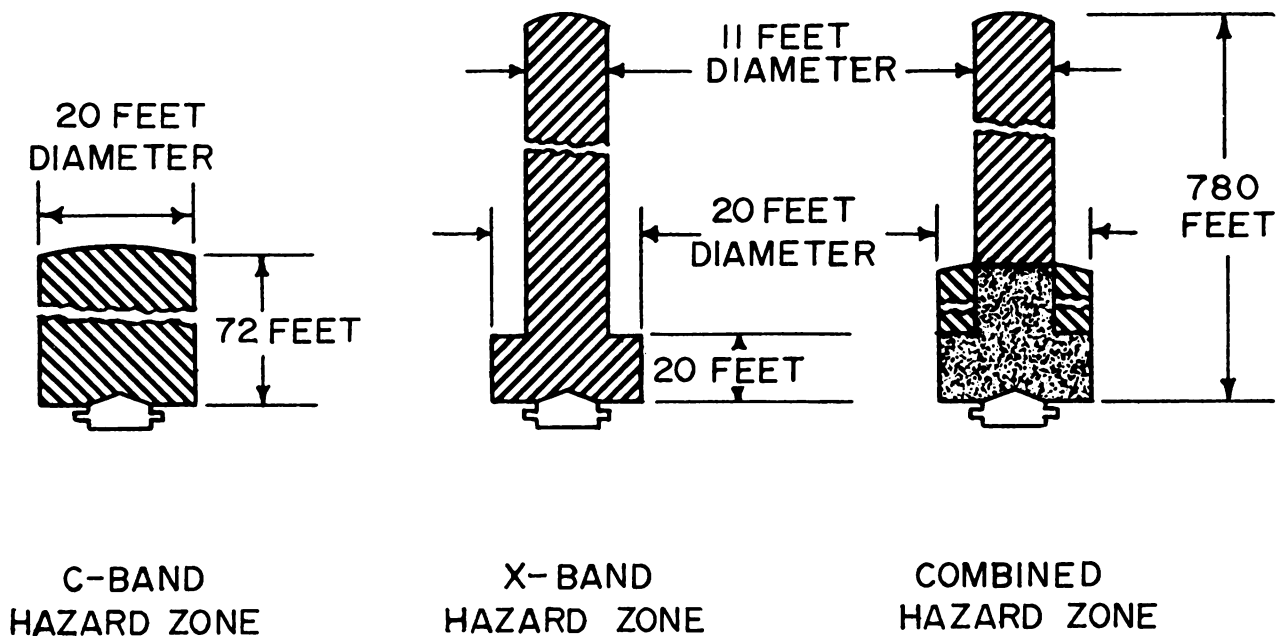
14. Do not use test equipment known to be in poor condition.

15. High-voltage high-capacity capacitors should be discharged with a grounding stick having approximately 10 ohms in series with the ground line. Where neither terminal of a capacitor is grounded, short the capacitor terminals to each other.

16. Do Not depend upon door switches or interlocks for protection but shut down motor generators or other power equipment. Under no circumstances should gate, door, or safety interlock switches be removed, short-circuited, or tampered with in any way, other than by authorized maintenance personnel.

17. Do Not operate any antenna or director drive system until all personnel are clear of the path of motion.

18. Personnel working with or near high voltages should be familiar with the methods of artificial respiration. Such information should be obtained from the ship's medical department.



APPENDIX III

RADAR EQUIPMENT NOMENCLATURE

Nomenclature designations are used primarily as the short title of equipments. These designations are unclassified, whereas the actual name of the equipment may sometimes be classified.

The nomenclature system used by the military services to identify electronic equipment and independent units that are not part of specific equipment is called the Joint Electronic Type Designation System (AN system) for communication and electronic equipments.

The AN nomenclature is assigned to:

1. Complete sets of equipment and major components of military design.
2. Groups of articles of either commercial or military design which are grouped for a military purpose.
3. Major articles of military design which are not a part of, or used with, a set.
4. Commercial articles when nomenclature will facilitate military identification or procedures.

AN nomenclature is not assigned to:

1. Articles cataloged commercially except when nomenclature will facilitate military identification or procedures.
2. Minor components of military design for which other adequate means of identification are available.
3. Small parts such as capacitors and resistors.
4. Articles having other adequate identification in American War Standards or Joint Army-Navy specifications.

EQUIPMENT INDICATOR LETTERS

Complete systems of equipments are designated by three indicator letters that follow AN/ and signify (1) Kind of installation, (2) Type of equipment, and (3) Purpose. Using AN/SPG-49 as an example, check the equipment indicator letters in the following table:

EQUIPMENT INDICATOR LETTERS

Installation	Type of Equipment	Purpose
A—Airborne (installed and operated in aircraft)	A—Invisible light, heat radiation	A—Auxiliary assemblies (not complete operating sets)
B—Underwater mobile, submarine	B—Pigeon	B—Bombing
C—Air transportable	C—Carrier	C—Communications (receiving and/or
	D—Radiac	
	E—Nupac	

Appendix III—RADAR EQUIPMENT NOMENCLATURE

Installation	Type of Equipment	Purpose
(inactivated; do not use)	F—Photographic	transmitting)
D—Pilotless carrier	G—Telegraph or tele-type	D—Direction finder
F—Fixed	I—Interphone or public address	G—Fire control or searchlight directing
G—Ground, general ground use (includes two or more ground installations)	J—Electromechanical (not otherwise covered)	H—Recording (photographic, meteorological, or sound)
K—Amphibious	K—Telemetering	L—Searchlight control (inactivated; use "G")
M—Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment)	L—Countermeasures	M—Maintenance and test assemblies (including tools)
P—Pack or portable (animal or man)	M—Meteorological	N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach, and landing)
S—Water surface craft	N—Sound in air	P—Reproducing (photographic and/or sound)
T—Ground, transportable	P—Radar	Q—Special, or combination of purposes
U—General utility (includes two or more general installation classes, airborne, shipboard, and ground)	Q—Sonar or underwater sound	R—Receiving, passive detecting
V—Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, etc., such as tank)	R—Radio	S—Detecting and/or range and bearing
	S—Special types, magnetic, etc., or combinations of types.	T—Transmitting
	T—Telephone (wire)	W—Control
	V—Visual or visible light	X—Identification and recognition
	W—Armament (peculiar to armament, not otherwise covered)	
	X—Facsimile or television	

AN indicates the equipment was assigned the type number in the AN system. "S" of the indicator letters, as shown in the installation column, means that the equipment is installed on a water surface craft. "P" in the type of equipment column signifies that the equipment is radar; and "G" in the purpose column indicates that the equipment is used for fire control or searchlight directing. The number 49 following the letters shows that it is the forty-ninth model designed for surface radar equipment. Any modification to the equipment will be indicated by adding A, B, etc., after the model number.

APPENDIX IV

STANDARD METRIC SYSTEM PREFIXES AND RADAR BAND DESIGNATION

STANDARD METRIC SYSTEM PREFIXES

Multiples and submultiples	Prefixes	Symbol	Multiples and submultiples	Prefixes	Symbol
10^{12}	tera	T	10^{-2}	centi	c
10^9	giga	G	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	u
10^3	kilo	k	10^{-9}	nano	n
10^2	hecto	h	10^{-12}	pico	p
10	deka	da	10^{-15}	femto	f
10^{-1}	deci	d	10^{-18}	atto	a

RADAR BAND DESIGNATION

Band	Frequency range Kmc*	Wavelength range cm*	Center of active region mc*
P	0.22-0.39	133-77	300
L	0.39-1.55	77-19	1,000
S	1.55-5.2	19-5.8	3,000
C†	3.9-6.2	7.7-4.8	5,500
X	5.2-10.9	5.8-2.7	9,000
K	10.9-36	2.7-0.83	25,000

* The limits given are approximate as no formal standards exist.

† The C-band is composed of adjoining portions of the S and X bands.

Microwave components are sometimes designated by their design wavelength range in cm.

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